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Henrikson et al.

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(54) **GOLF CLUB HEADS WITH TURBULATORS AND METHODS TO MANUFACTURE GOLF CLUB HEADS WITH TURBULATORS**

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(73) Assignee: **KARSTEN MANUFACTURING CORPORATION**, Phoenix, AZ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/093,967**

(22) Filed: **Dec. 2, 2013**

(65) **Prior Publication Data**

US 2014/0087893 A1 Mar. 27, 2014

Related U.S. Application Data

(63) Continuation-in-part of application No. 13/536,753, filed on Jun. 28, 2012, now Pat. No. 8,608,587.

(60) Provisional application No. 61/775,982, filed on Mar. 11, 2013, provisional application No. 61/553,428, filed on Oct. 31, 2011, provisional application No. 61/651,392, filed on May 24, 2012.

(51) **Int. Cl.**

A63B 53/04	(2006.01)
A63B 49/06	(2006.01)
A63B 59/00	(2015.01)

(52) **U.S. Cl.**

CPC ***A63B 53/0466*** (2013.01); ***A63B 49/06*** (2013.01); *A63B 53/047* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC A63B 53/0466; A63B 2059/0011; A63B 2225/01; A63B 2053/0433; A63B 2053/0408; A63B 2053/0437; A63B 2059/0003; A63B 2053/0412; A63B 49/06; A63B 53/047; A63B 53/0487

USPC 473/324, 327, 328, 345, 409, 226, 228, 473/344; D21/733, 752, 759

See application file for complete search history.

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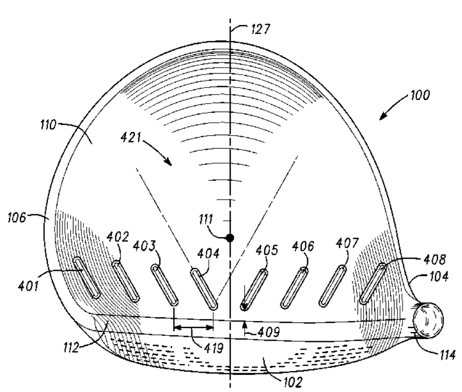
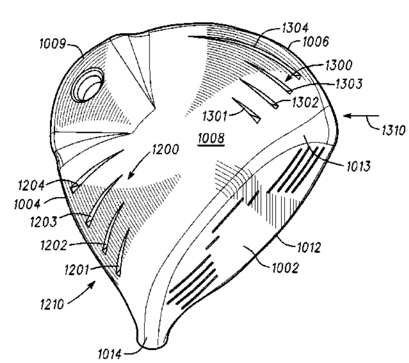
Primary Examiner — Sebastiano Passaniti

(57) **ABSTRACT**

A golf club head including a face portion defining a loft plane, a rear portion opposite to the face portion, a heel portion, a toe portion opposite to the heel portion, a crown portion having a crown surface extending between the face portion, the rear portion, the heel portion and the toe portion, a sole portion opposite to the crown portion and having a sole surface extending between the face portion, the rear portion, the heel portion and the toe portion, and a leading edge portion between the face portion and the crown portion, the leading edge portion defining a leading edge plane forming a leading edge angle with the loft plane; and a plurality of crown turbulators disposed on the crown surface, each crown turbulator having a front portion defining a portion of the crown turbulator being closest to the face portion, the front portion of at least one of the plurality of crown turbulators being at least partly located on the leading edge portion and between the leading edge plane and the rear portion, but not extending beyond the leading edge plane.

17 Claims, 20 Drawing Sheets





(52) **U.S. Cl.**
CPC *A63B53/0487* (2013.01); *A63B 2053/0408* (2013.01); *A63B 2053/0412* (2013.01); *A63B 2053/0433* (2013.01); *A63B 2053/0437* (2013.01); *A63B 2059/0003* (2013.01); *A63B 2059/0011* (2013.01); *A63B 2225/01* (2013.01); *Y10T 29/49826* (2015.01)

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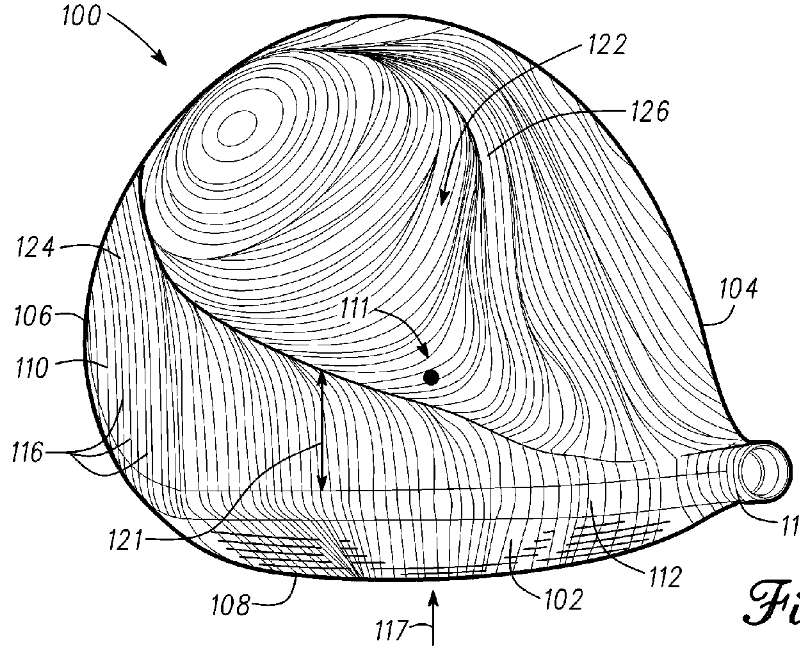
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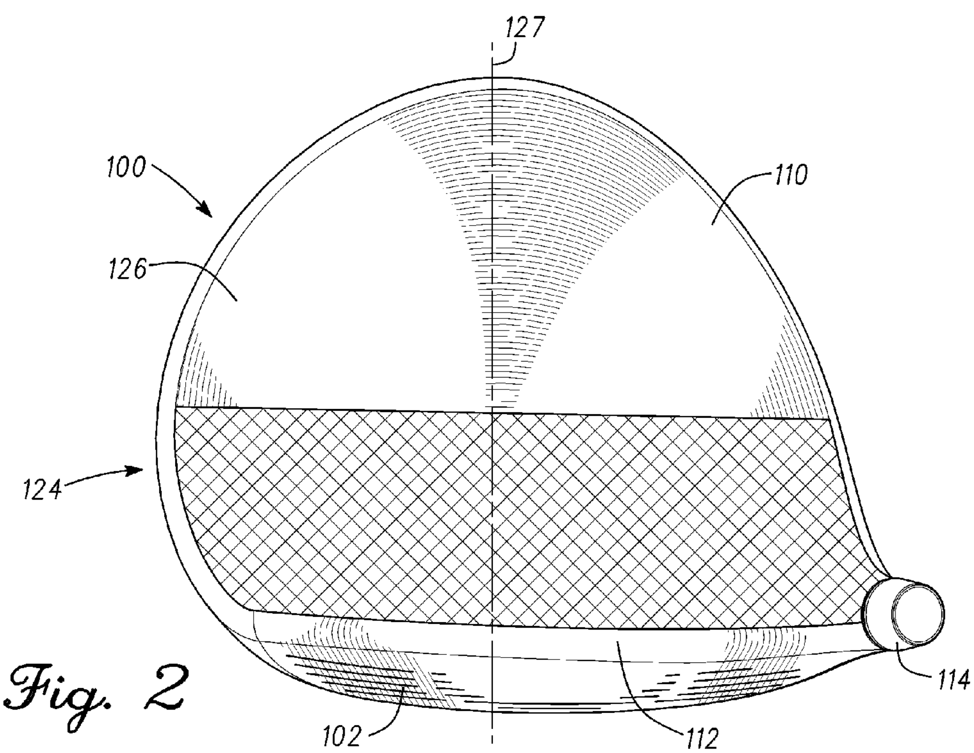
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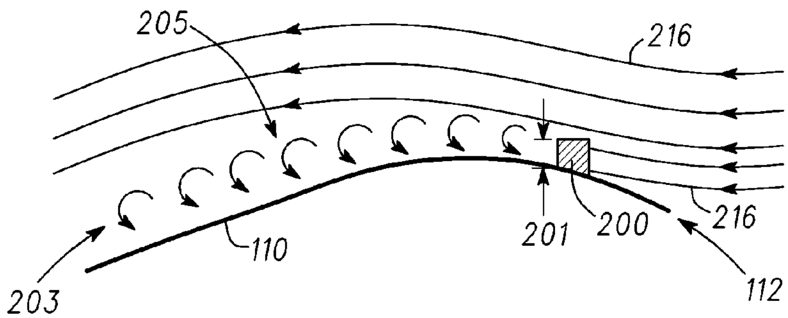

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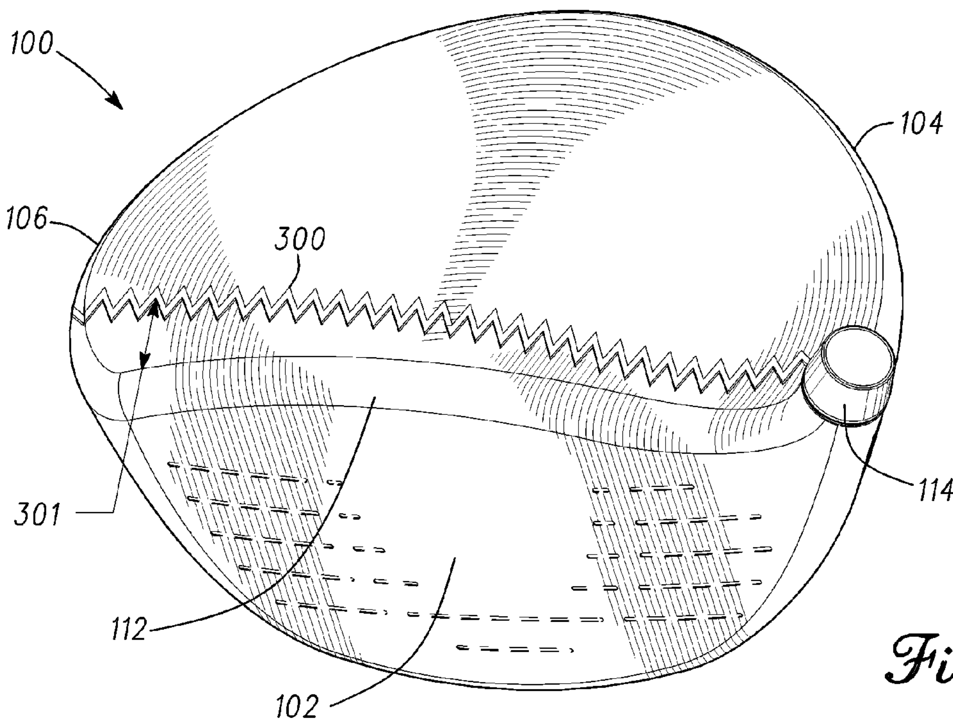

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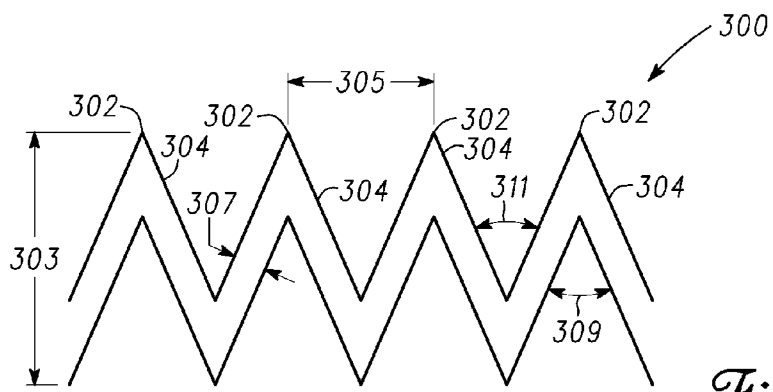

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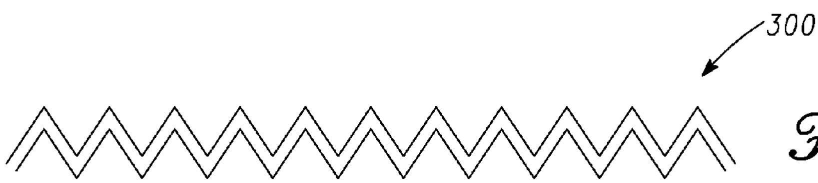

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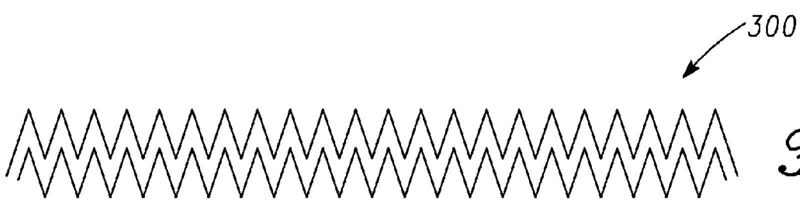
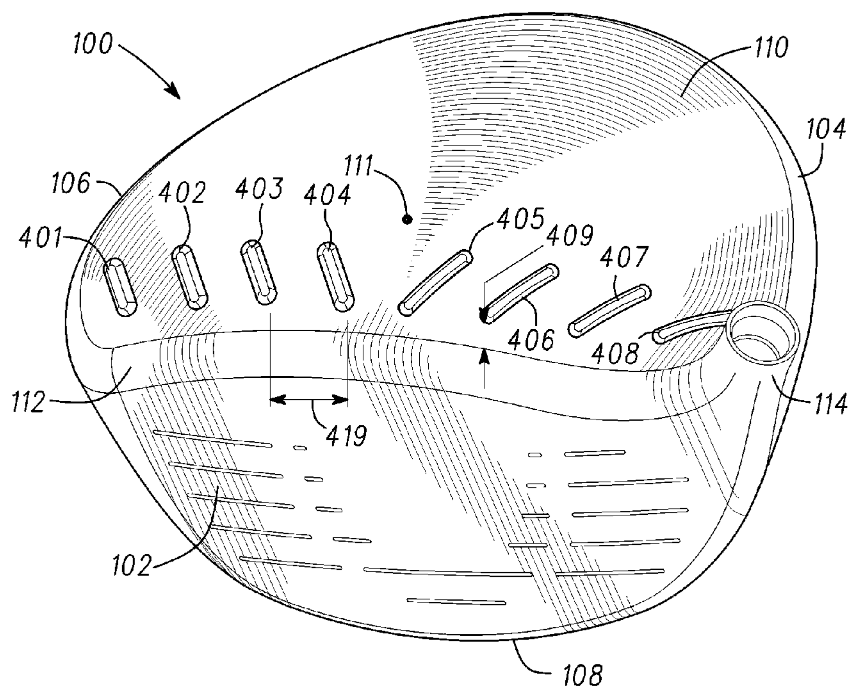


Fig. 7

Fig. 8

Fig. 9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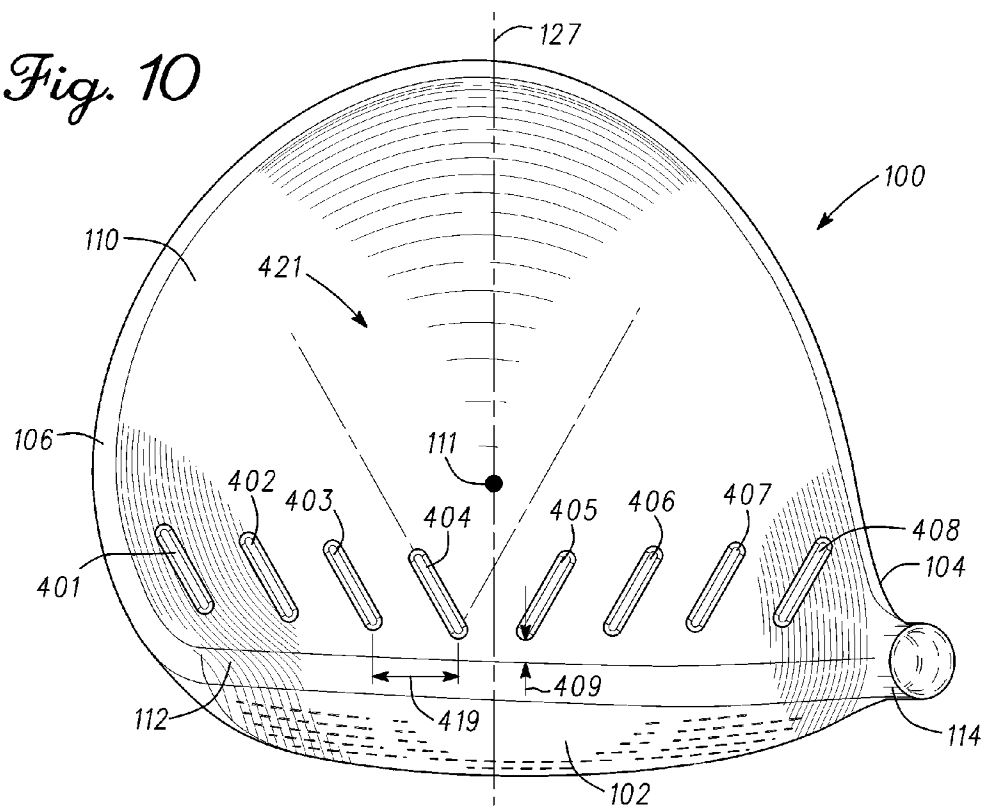
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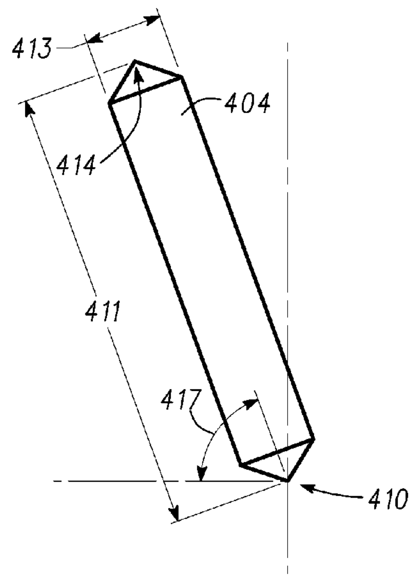

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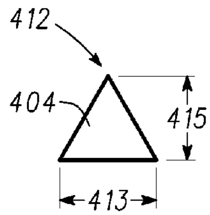

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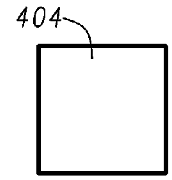
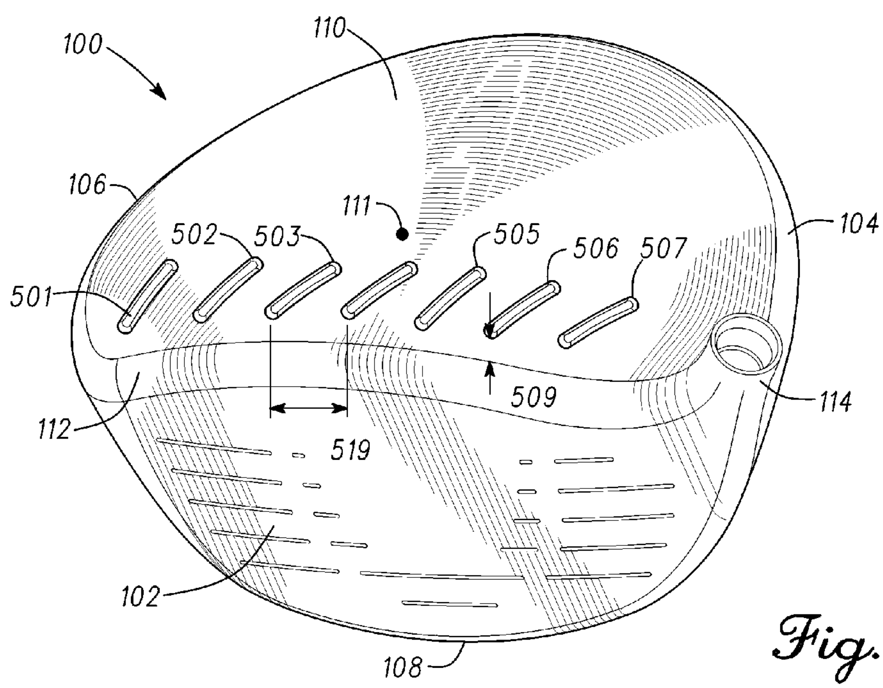


Fig. 13

Fig. 14



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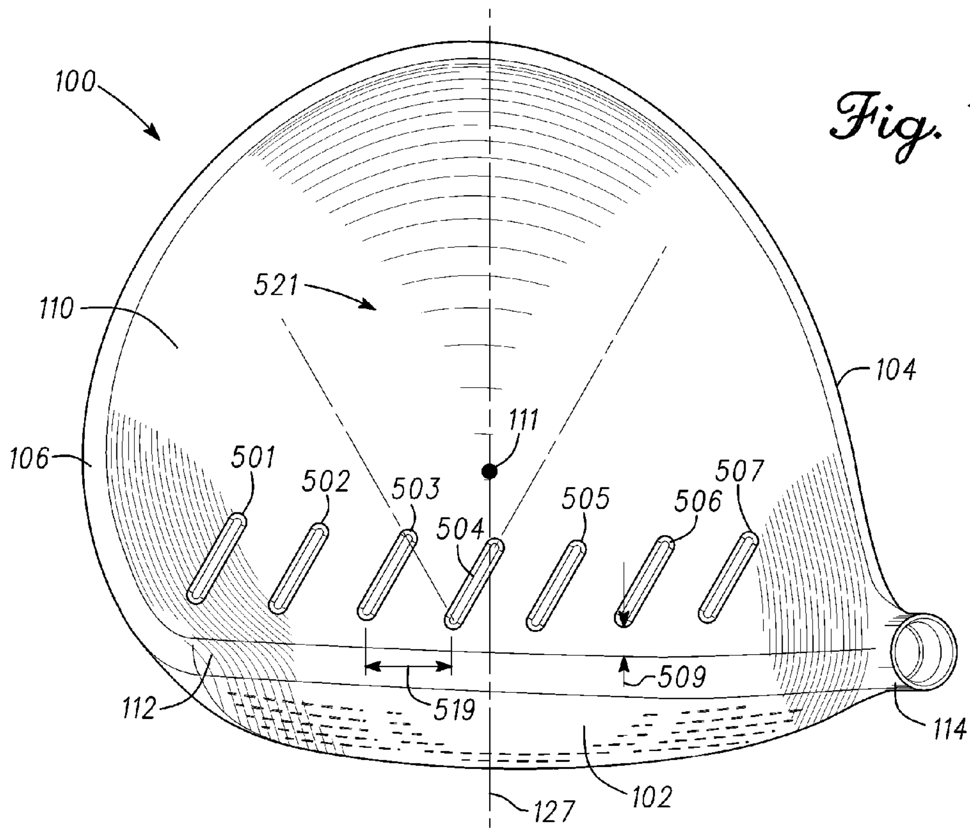

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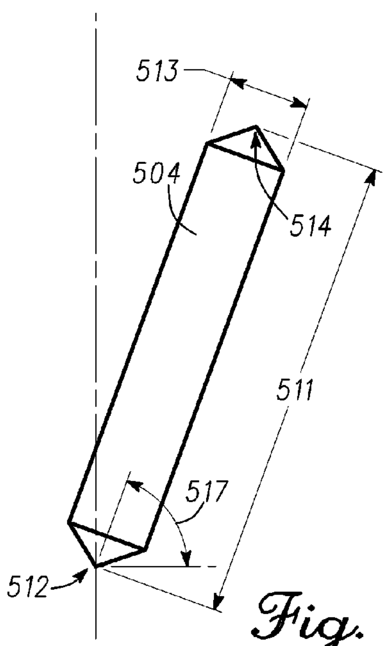

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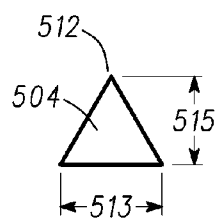

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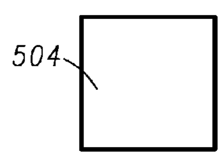
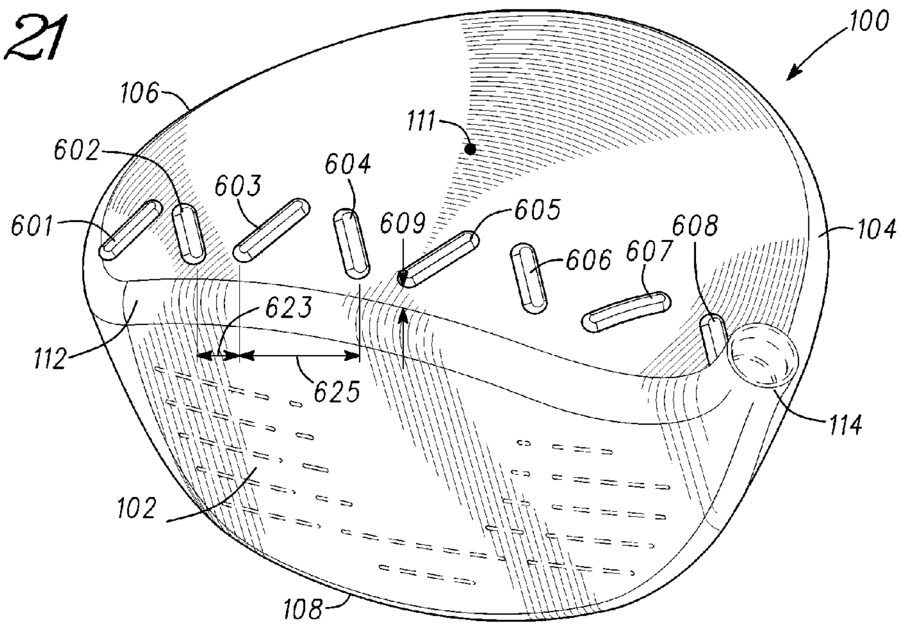


Fig. 19

Fig. 20

Fig. 21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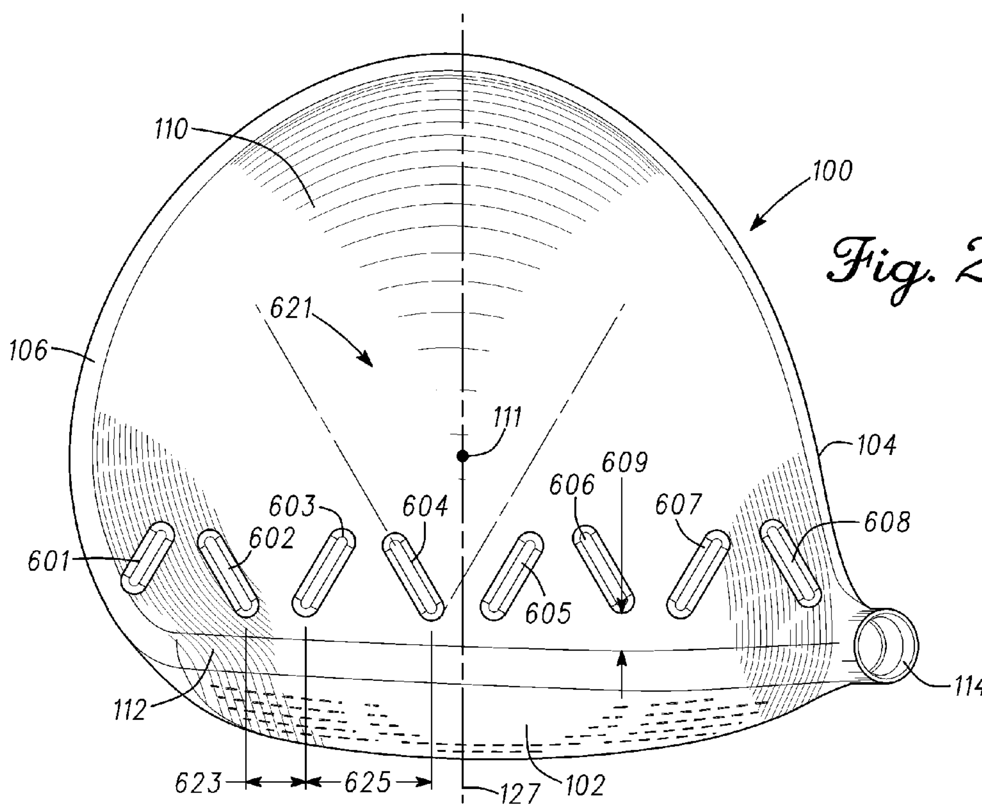
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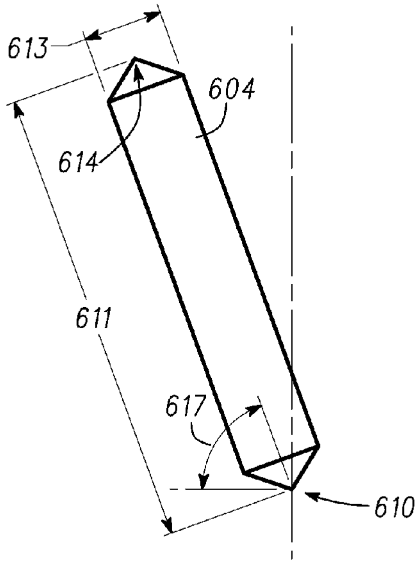
Fig. 22



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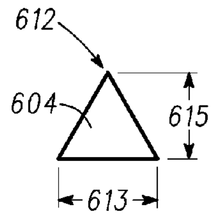

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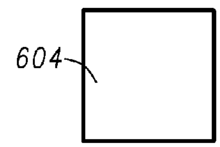

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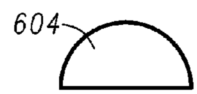

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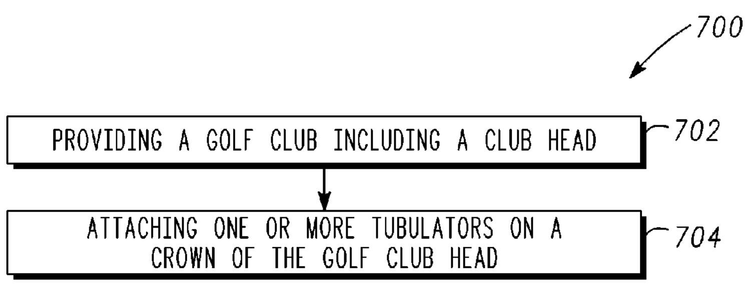

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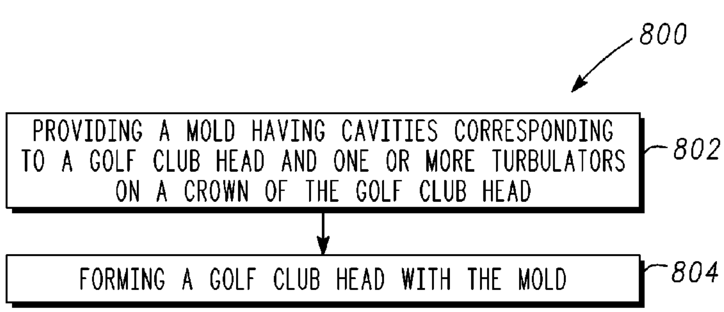

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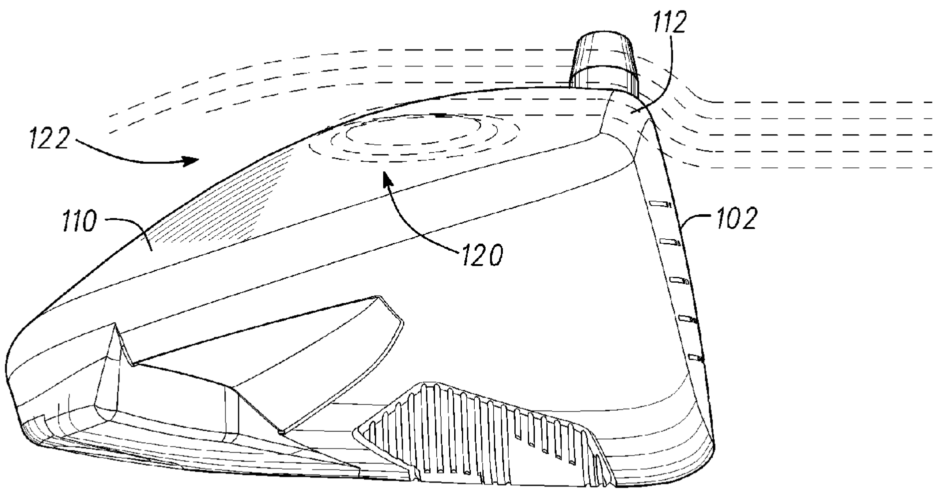

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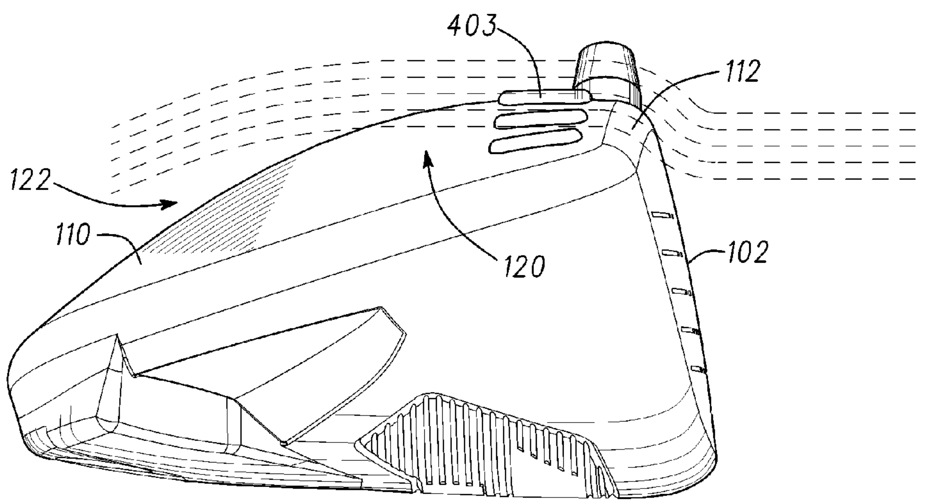

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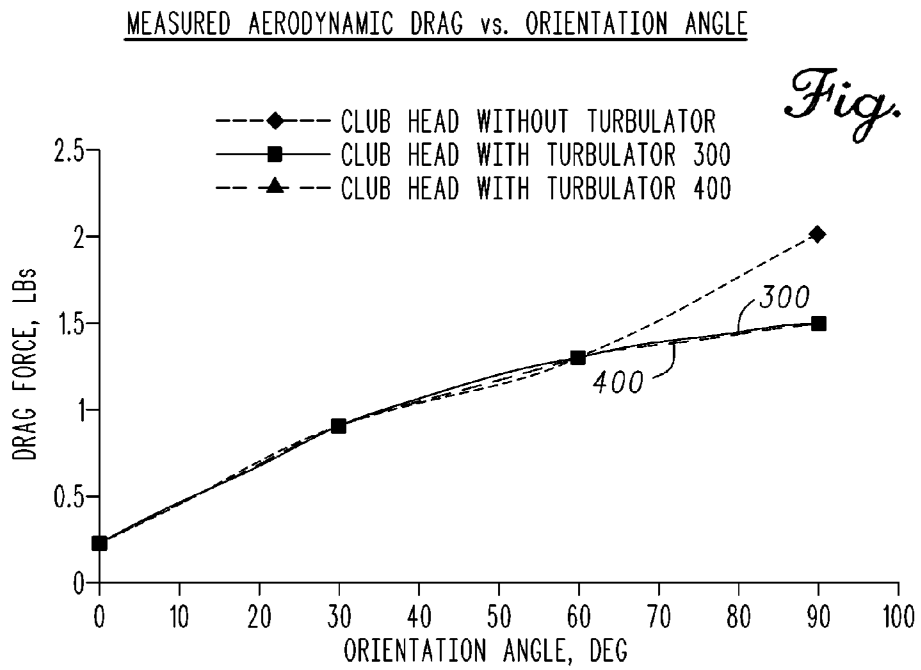
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CLUB HEAD WITHOUT TURBULATOR
CLUB HEAD WITH TURBULATOR 300
CLUB HEAD WITH TURBULATOR 400
DRAG FORCE, LBs
ORIENTATION ANGLE, DEG
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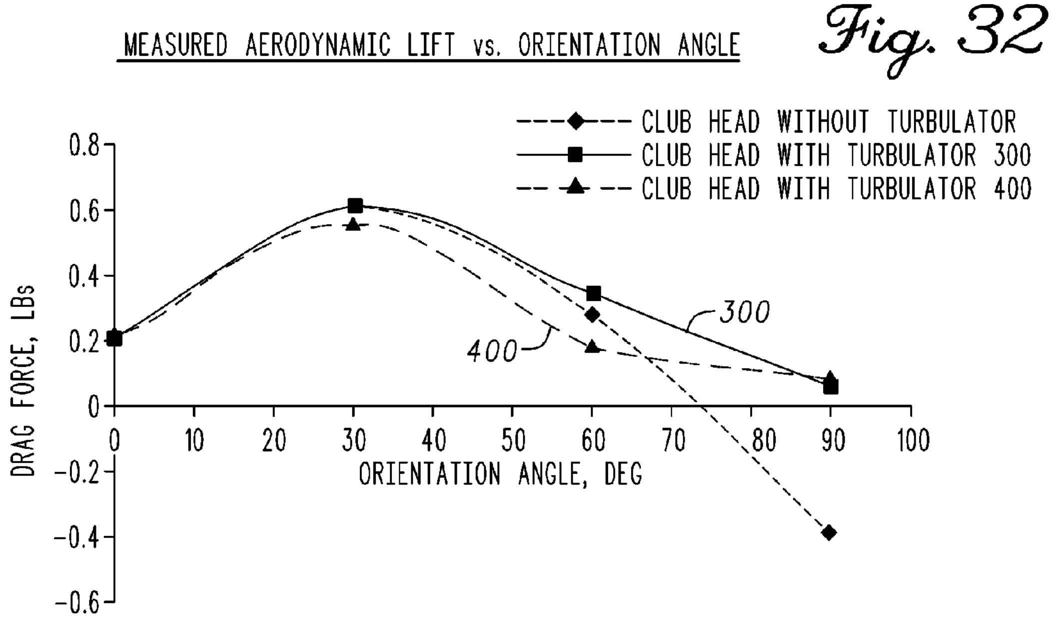
Fig. 31


MEASURED AERODYNAMIC LIFT vs. ORIENTATION ANGLE
CLUB HEAD WITHOUT TURBULATOR
CLUB HEAD WITH TURBULATOR 300
CLUB HEAD WITH TURBULATOR 400
DRAG FORCE, LBs
ORIENTATION ANGLE, DEG
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400
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−0.4
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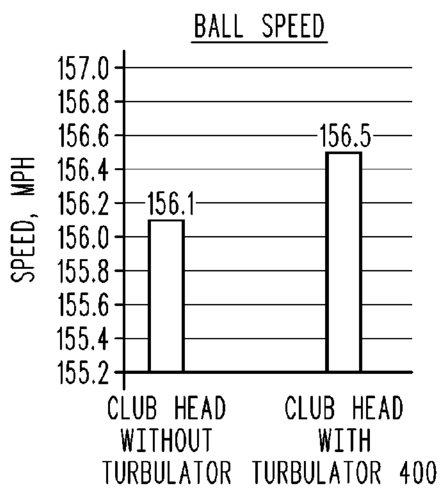
Fig. 32



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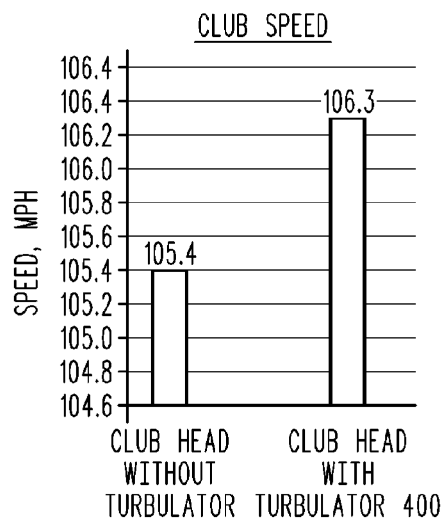

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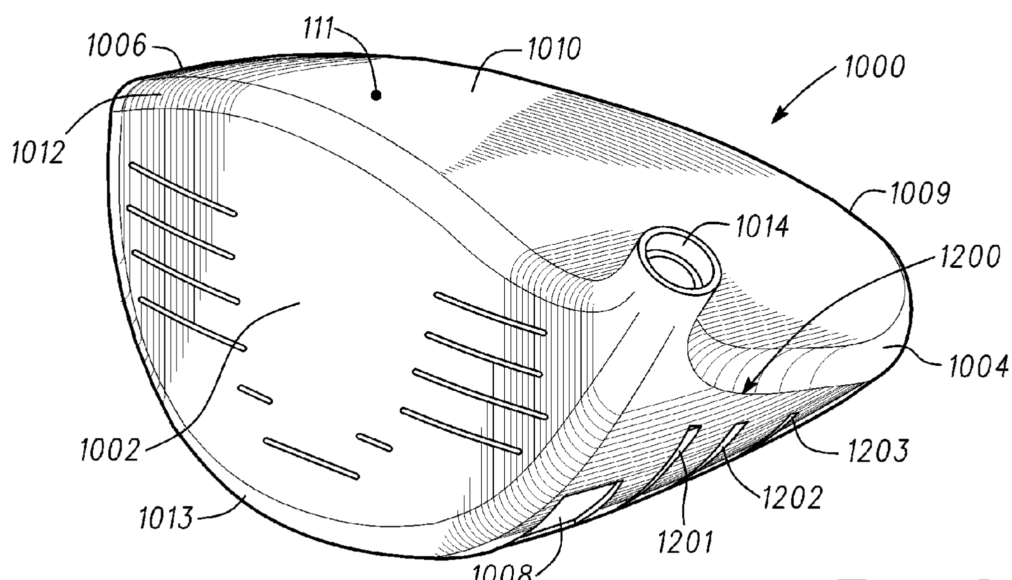

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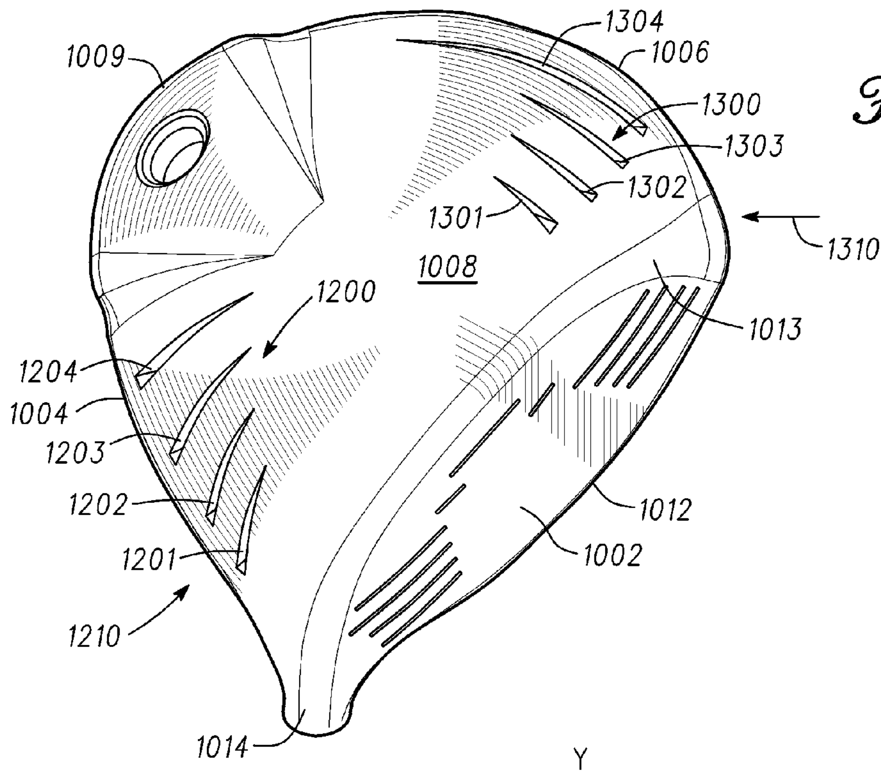
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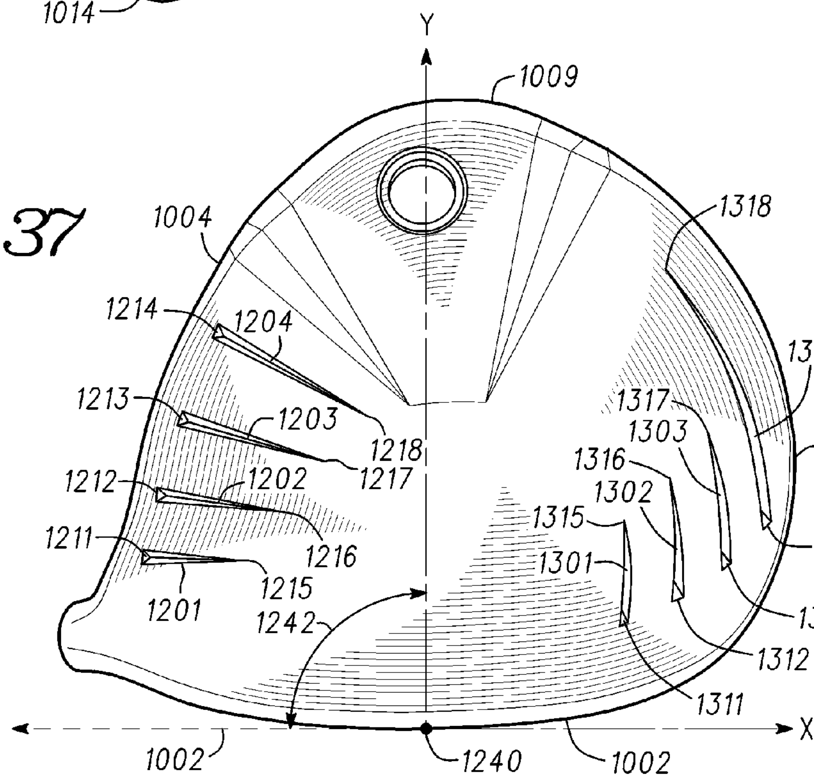
Fig. 36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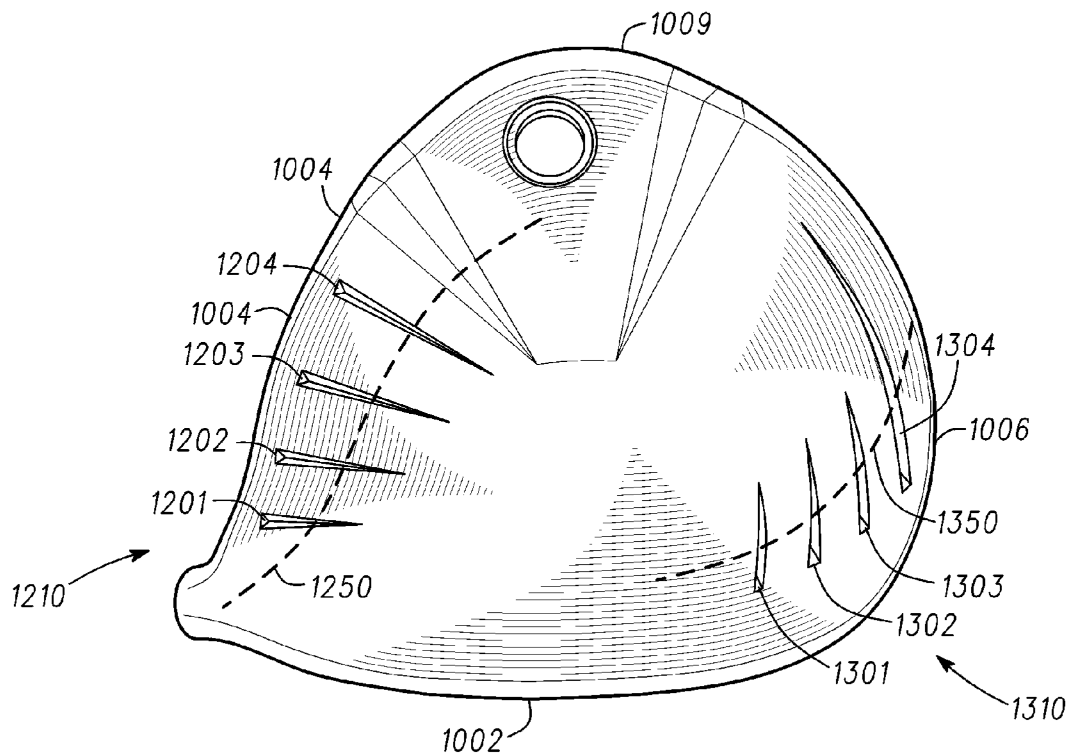
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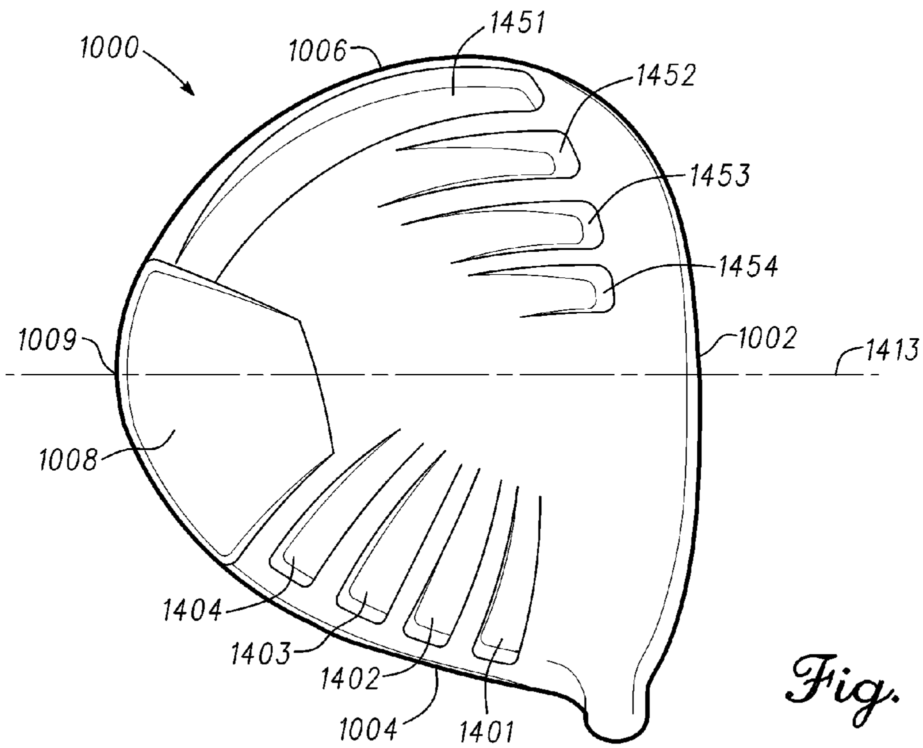
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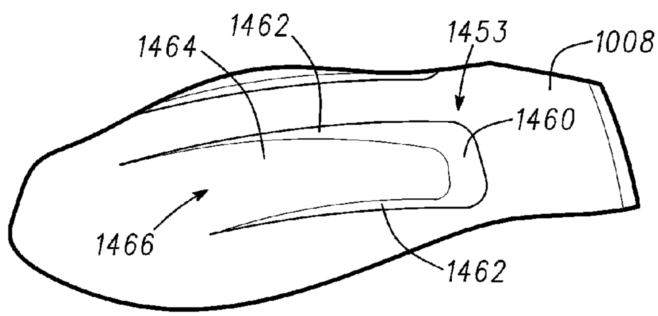
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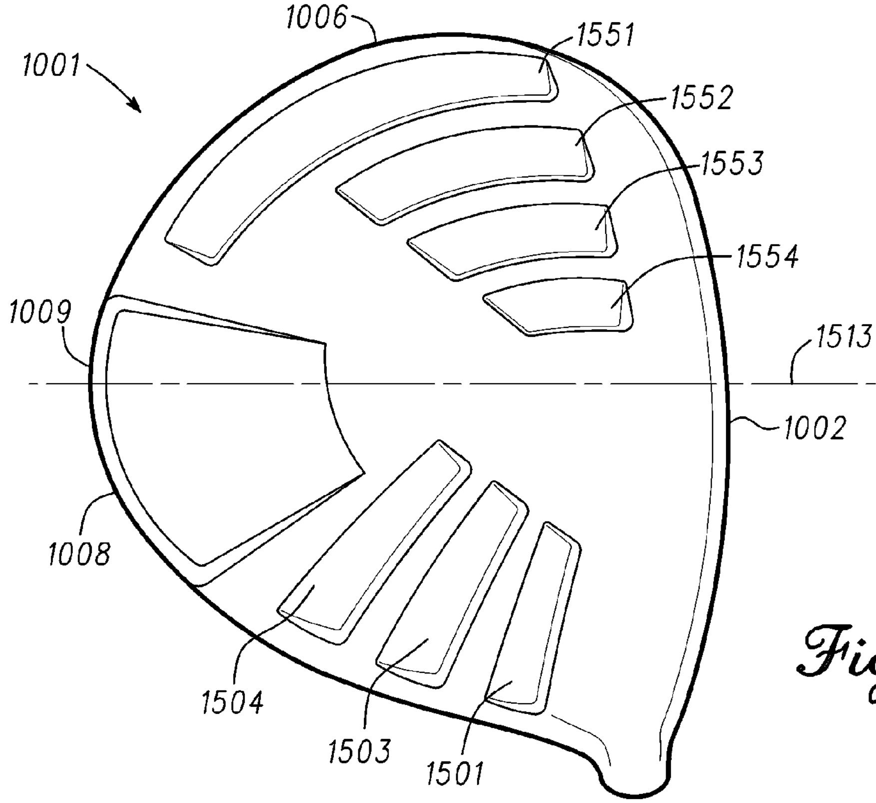
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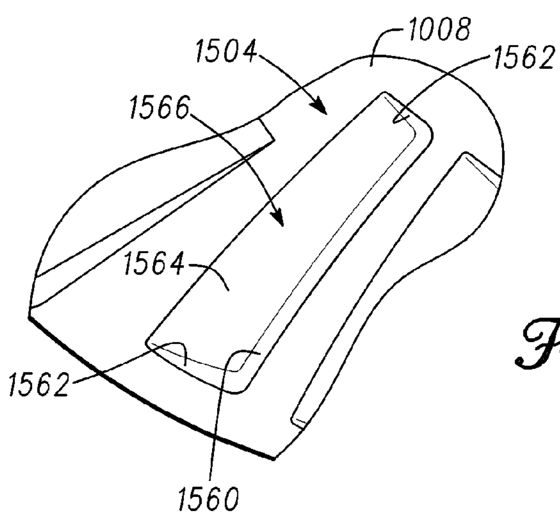
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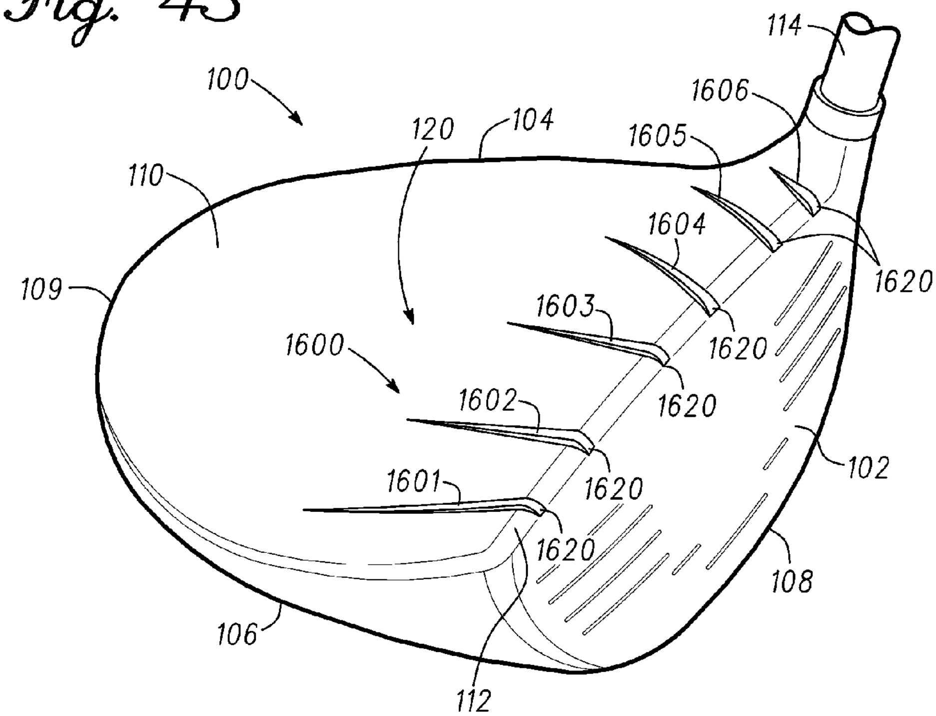
Fig. 42

Fig. 43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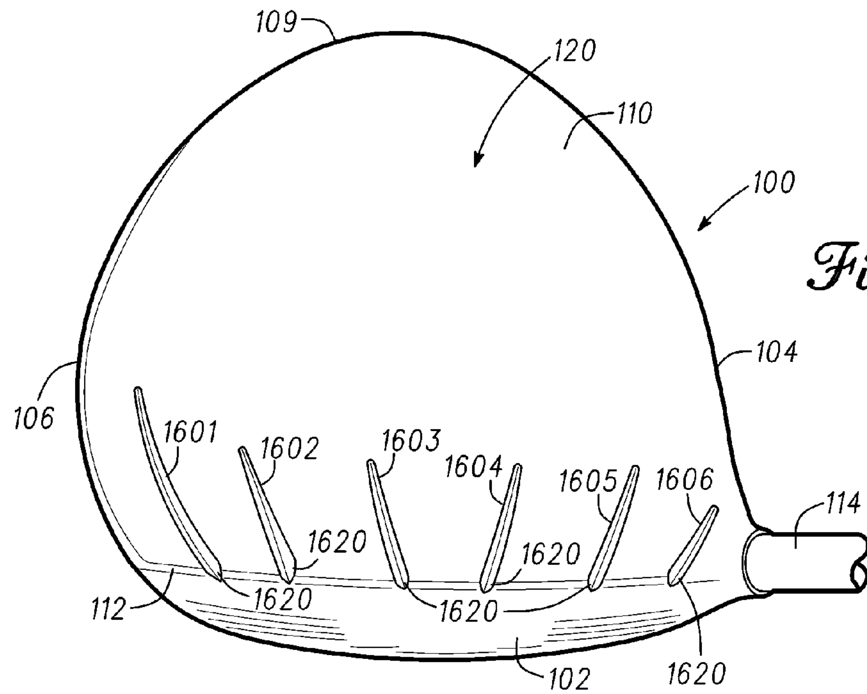
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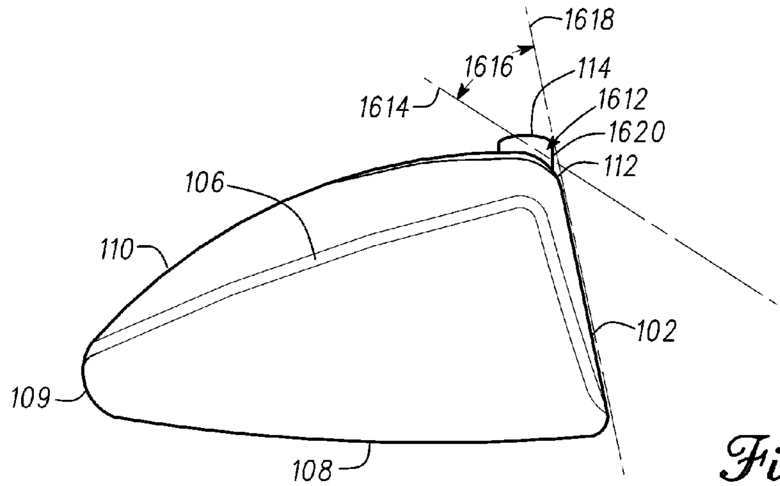
Fig. 44



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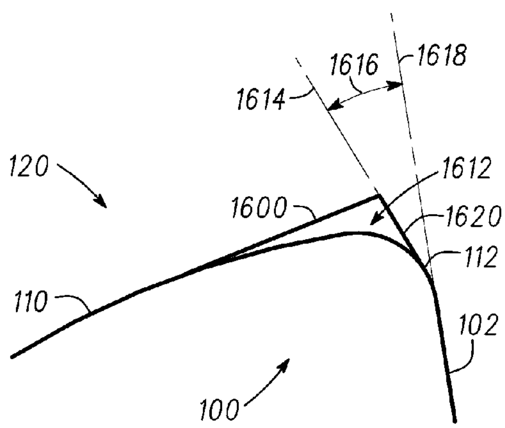

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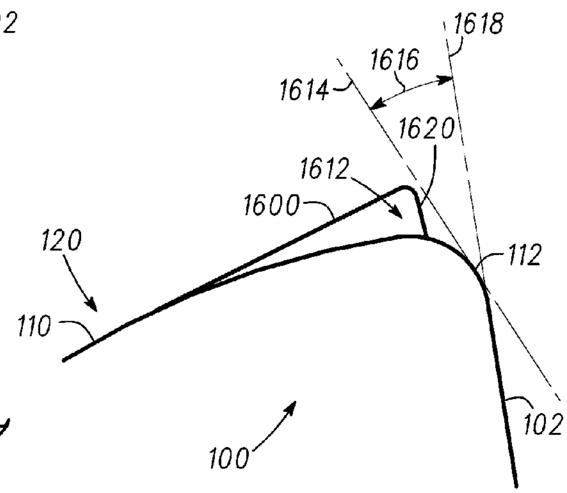

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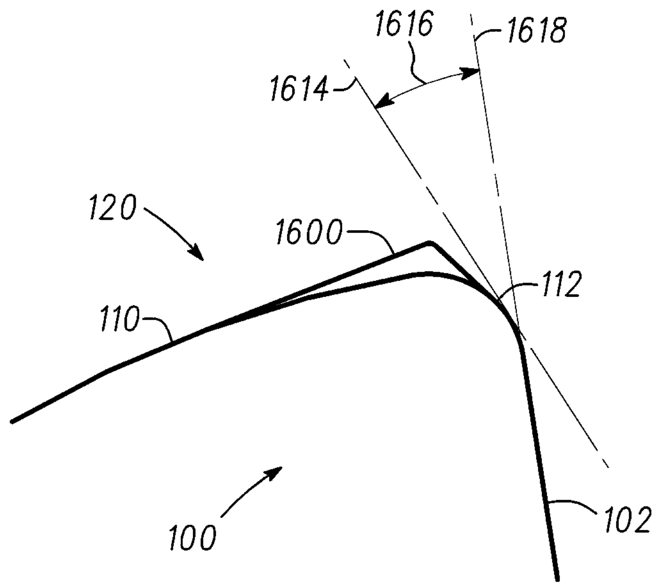
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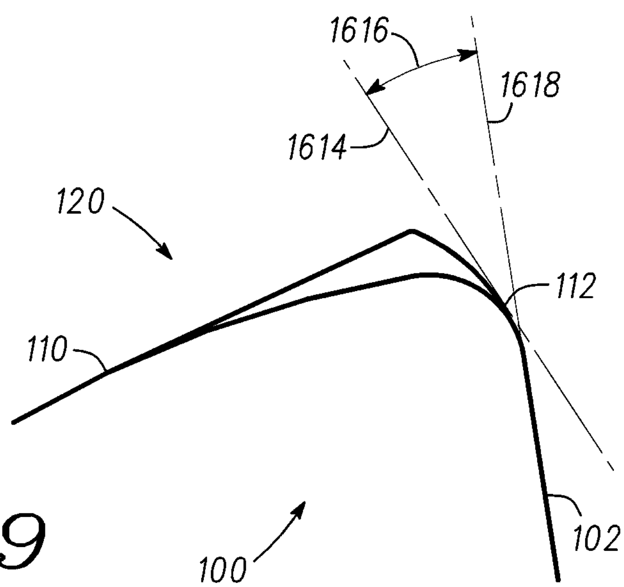
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100
102

Fig. 49

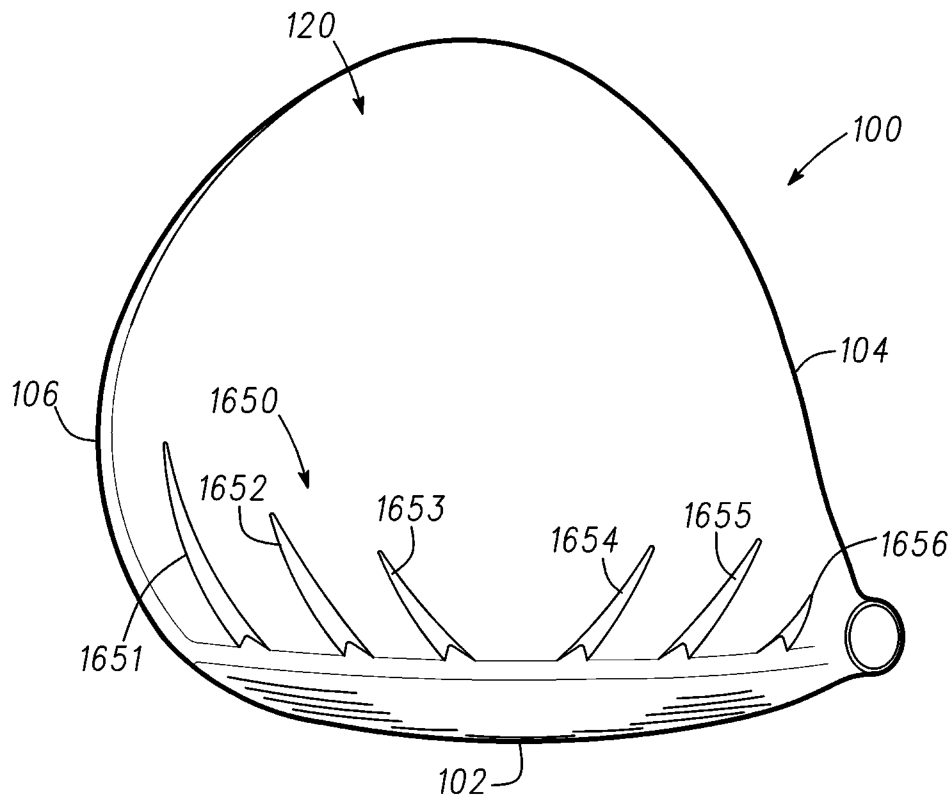

Fig. 50

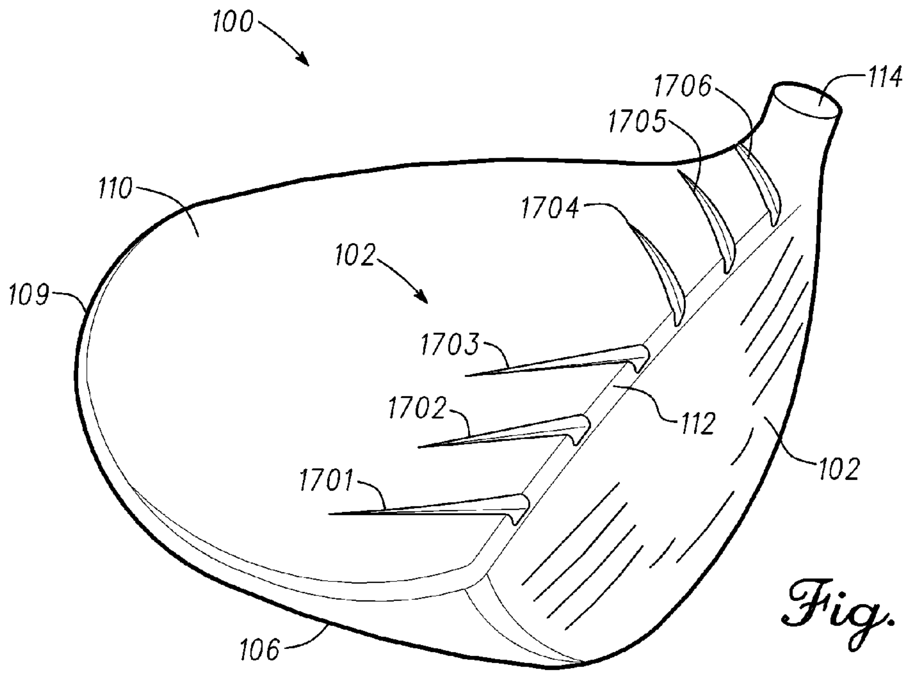
100
1706
114
1705
110
1704
102
109
1703
1702
112
102
1701
106

Fig. 51

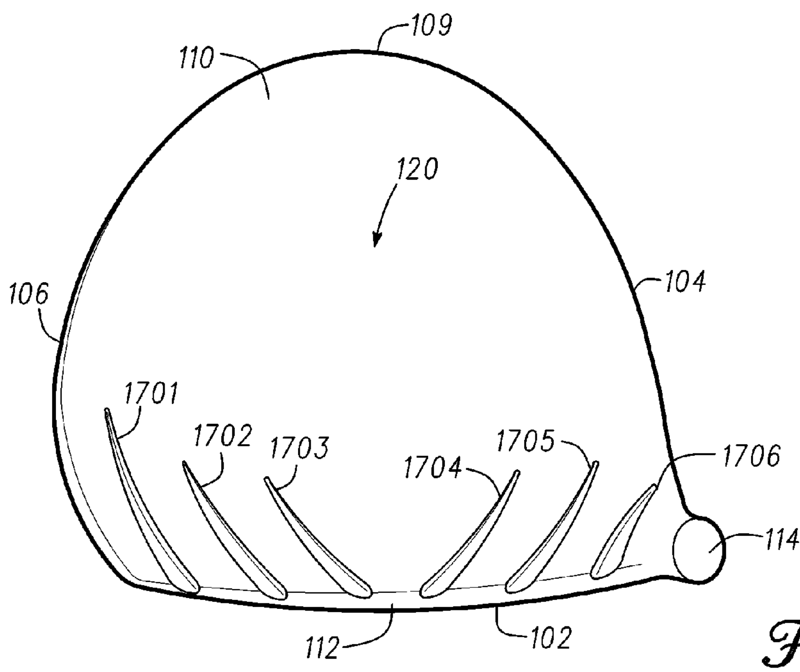
109
110
120
106
104
1701
1702
1703
1704
1705
1706
114
112
102

Fig. 52

GOLF CLUB HEADS WITH TURBULATORS AND METHODS TO MANUFACTURE GOLF CLUB HEADS WITH TURBULATORS

RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/775,982, filed on Mar. 11, 2013, and is a continuation-in-part of U.S. patent application Ser. No. 13/536,753, filed on Jun. 28, 2012, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/553,428, filed on Oct. 31, 2011, and U.S. Provisional Patent Application Ser. No. 61/651,392, filed on May 24, 2012. All of the above-noted applications are incorporated by reference.

FIELD

The present application generally relates to golf clubs, and more particularly, to golf club heads with turbulators and methods to manufacture golf club heads with turbulators.

BACKGROUND

When air flows over a golf club head, viscous forces near the surface of the club head create a velocity gradient from the surface to the free stream region. Accordingly, air flow velocity near the surface may be relatively slow and gradually increases toward the free stream velocity, which is the air flow region where air velocity is not influenced by the club head. This velocity gradient region is called a boundary layer. Flow separation occurs when the boundary layer travels on the golf club head far enough against an adverse pressure gradient that the air flow velocity in the boundary layer relative to the surface of the club head falls almost to zero. The air flow becomes detached from the surface of the club head and takes the form of eddies and vortices. Flow separation may result in increased drag, which may be caused by the pressure differential between the front and rear surfaces of the club head. The increased drag may reduce the speed of the club head, which in turn may lower the velocity of a golf ball that is struck by the club head.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top perspective view of a club head showing air flow streamlines on the club head.

FIG. **2** is a top perspective view of a club head shown front and aft regions of a crown of the club head.

FIG. **3** is a schematic cross-sectional diagram of a turbulator according to one embodiment.

FIG. **4** is a perspective view of a club head having a turbulator according to one embodiment.

FIG. **5** is a schematic diagram of the turbulator of FIG. **4**.

FIGS. **6-8** show examples of different turbulators according to the embodiment of FIG. **4**.

FIGS. **9** and **10** are perspective views of a club head having a turbulator according to one embodiment.

FIG. **11** is a schematic diagram of a section of the turbulator of FIGS. **9** and **10**.

FIGS. **12-14** show different cross-sectional diagrams of turbulators according to the embodiment of FIGS. **9** and **10**.

FIGS. **15** and **16** are perspective views of a club head having a turbulator according to one embodiment.

FIG. **17** is a schematic diagram of a section of the turbulator of FIGS. **15** and **16**.

FIGS. **18-20** show different cross-sectional diagrams of turbulators according to the embodiment of FIGS. **15** and **16**.

FIGS. **21** and **22** are perspective views of a club head having a turbulator according to one embodiment.

FIG. **23** is a schematic diagram of a section of the turbulator of FIGS. **21** and **22**.

FIGS. **24-26** show different cross-sectional diagrams of turbulators according to the embodiment of FIGS. **21** and **22**.

FIG. **27** is a flow chart showing a method of manufacturing a club head with turbulators according to one embodiment.

FIG. **28** is a flow chart showing a method of manufacturing a club head with turbulators according to another embodiment.

FIG. **29** shows a schematic view based on actual airflow visualization experiments of airflow over a club head without turbulators.

FIG. **30** shows a schematic view based on actual airflow visualization experiments of airflow over the club head of FIG. **29** with turbulators.

FIG. **31** is a graph showing measurements of drag force vs. orientation angle.

FIG. **32** is a graph showing measurements of lift force vs. orientation angle.

FIG. **33** is a graph showing measurements of ball speed.

FIG. **34** is a graph showing measurements of club speed.

FIGS. **35-38** are different perspective views of a club head having sole turbulators according to one embodiment.

FIG. **39** is a perspective bottom view of a club head having sole turbulators according to one embodiment.

FIG. **40** is a perspective view of a portion of the club head of FIG. **39**.

FIG. **41** is a perspective bottom view of a club head having sole turbulators according to one embodiment.

FIG. **42** is a perspective view of a portion of the club head of FIG. **41**.

FIGS. **43** and **44** are perspective side and top views, respectively, of a club head having turbulators according to one embodiment.

FIG. **45** is a side perspective view of a club head having turbulators according to one embodiment.

FIGS. **46-49** are schematic diagrams of turbulator configurations according to several embodiments.

FIG. **50** is a perspective top view of a club head having turbulators according to one embodiment.

FIGS. **51** and **52** are perspective side and top views, respectively, of a club head having turbulators according to one embodiment.

DETAILED DESCRIPTION

Referring to FIG. **1**, a golf club head **100** is shown, which includes a face **102** that extends horizontally from a heel end **104** to a toe end **106** and vertically from a sole **108** to a crown **110**. A transition region between the face **102** and the crown **110** defines a leading edge **112**. The highest point on the crown **110** defines an apex **111**. The club head **100** also includes a hosel **114** for receiving a shaft (not shown). The club head **100** is a wood-type club head. However, the present disclosure is not limited to wood-type club heads and applies to any type of golf club head (e.g., a driver-type club head, a fairway wood-type club head, a hybrid-type club head, an iron-type club head, a wedge-type club head, or a putter-type club head). The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

FIG. **1** shows an exemplary air flow pattern on the club head **100** with streamlines **116**. Air flowing in the direction of the arrow **117** flows over the crown **110** from the leading edge

112 toward the rear section of the crown **110**. The airflow may remain attached to the crown **110** from the leading edge **112** to a separation region **120** located at a certain separation distance **121** from the leading edge **112**. The separation may occur in a narrow strip on the crown **110**, hence the separation region **120** may also be referred to herein as a separation line **120**. As shown in FIG. **1**, the distance **121** may vary from the heel end **104** to the toe end **106** depending on the physical characteristics of the club head **100**. At the separation region **120**, the airflow detaches from the crown **110** and creates a wake region **122**, which is defined by the airflow becoming turbulent or forming eddies and vortices in the free stream region. The pressure differential between the wake region **122** and the attached flow region on the crown **110** creates a pressure drag on the club head **100**. The pressure drag reduces the speed of the club head **100**, hence affecting the speed by which a ball is hit with the club head **100**. To maintain the air flow attached on the crown **110** for a longer distance **121**, the air flow in the boundary layer before the separation region **120** can be energized to delay air flow detachment or to move the separation region **120** farther back on the crown **110**. To energize the boundary layer, which may be laminar upstream of the separation region **120**, the boundary layer can be made turbulent (or more turbulent if the flow is turbulent) upstream of the separation region **120**.

To delay air flow separation or detachment as described above, the golf club head **100** includes turbulators positioned on the crown **110** as described in detail below. Referring to FIG. **2**, the turbulators may be positioned in the front region **124** of the crown **110** and before the separation region **120** to delay air flow separation or move the separation region **120** toward the rear region **126** of the crown **110**. A schematic diagram of an exemplary turbulator **200** is shown in cross section in FIG. **3**. The turbulator **200** projects upward from the crown **110** at a height **201** such that it is inside the boundary layer **203**. The turbulator **200** trips the air flowing over the crown **110** as shown by the streamline **216** to create turbulence **205** inside the boundary layer **203**. The turbulence energizes the boundary layer **203** to delay separation of the air flow on the crown **110** and move the separation region **120** toward the aft region **126** of the crown **110**. In other words, the turbulators according to the disclosure increase the distance **121** shown in FIG. **1**.

An example of a turbulator **300** is shown in FIG. **4**. The turbulator **300** energizes the boundary layer on the crown **110** by generating turbulence in the boundary layer. The turbulator **300** is located on the crown **110** at a constant or variable distance **301** downstream of the leading edge **112** and may extend from the hosel **114** or the heel end **104** to the toe and **106**. The turbulator **300** provides a plurality of projected surfaces in discrete or continuous form on the surface of the crown **110** at a height (not showing FIGS. **4-8**, but generally shown with reference number **201** in FIG. **3**). When the air flowing over the crown **110** encounters the projected surfaces of the turbulator **300**, the air trips and becomes turbulent inside the boundary layer to energize the boundary layer.

The turbulator **300** shown in the example of FIG. **4** is formed by a strip having a zigzag pattern. Referring to FIG. **5**, the zigzag pattern provides peaks **302** and swept back surfaces **304**. The peaks **302** and the swept back surfaces **304** provide continuous tripping of the air flow across the width **303** of the turbulator **300**. The peaks **302** are spaced apart by a distance **305** and the turbulator **300** has a thickness **307**, a height (not shown in FIGS. **4-8**), and surface characteristics that may affect air flow. The peaks **302** are defined by a peak angle **309** and the angle between two adjacent peaks **302** is defined by a valley angle **311**. Referring to FIGS. **6-8**, the width **303**, the distance **305**, the thickness **307**, the height and/or the angles **309** and **311** may be different for each application to provide a particular flow pattern over the crown **110**. The surface characteristics of the turbulator **300** may also vary to provide a certain flow pattern over the crown **110**. The surface characteristics of the turbulator **300** may refer to the roughness or smoothness of the top surface of the turbulator **300**. In the examples of FIGS. **6-8**, the turbulator **300** shown in FIG. **7** may provide greater turbulence in a boundary layer than the turbulator **300** of FIG. **6**. Accordingly, the turbulator **300** of FIG. **7** may be suitable in a certain application depending on the physical characteristics of the club head **100**. However, the turbulator **300** of FIG. **6** may be suitable for another type of club head **100**. Accordingly, each of the exemplary turbulators **300** of FIGS. **6-8** may be suitable for different club heads **100**.

The turbulator **300**, for example, may have a height that does not exceed 0.5 inches (1.27 cm). In one embodiment, the turbulator **300** may have a height that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). In one embodiment, the width **303** of the turbulator may be less than 0.75 inches (1.91 cm). The turbulator **300** may have a peak-to-peak distance **305** that contributes to the delay in airflow separation. The location of the turbulator **300** may vary depending on the physical characteristics of the club head **100** and the flow pattern on the crown **110**. The turbulator **300** may be located on the crown **110** at an oblique angle relative to the club face **102** as shown in FIG. **4**, or be parallel to the club face **102** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **102**. The turbulator **300** may be located in a curvilinear manner on the crown **110** based on the separation region **120** of a particular club head **100**. In one embodiment, the turbulator **300** is located between the club face **102** and the apex **111** of the crown **110**. Accordingly, the turbulator **300** may be located between the leading edge **112** and the apex **111** of the crown **110**. The turbulator **300** may be located on the crown **110** such that the swept back surfaces **304** form an angle of between 20° and 70° degrees relative to the centerline **127** (shown in FIG. **2**) of the club head **100**.

Referring to FIG. **4**, for example, the turbulator **300** may be a strip that extends from the heel end **104** to the toe end **106**. Additionally, the distance **301** increases from the heel end **104** to the toe end **106**. This increase in the distance **301** positions the turbulator to approximately follow the shape of the separation region **120** shown in FIG. **1**. Alternatively, the turbulator **300** may be a curved strip (not shown) that substantially follows the shape of the separation region **120**.

The width **303**, the distance **305**, the thickness **307**, the height and/or the angles **309** and **311** may be constant along the length of the turbulator as shown in FIGS. **6-8**. However, any one or all of noted parameters may vary along the turbulator **300** from the heel end **104** to the toe end **106** to provide a particular airflow effect. Furthermore, the surface characteristics of the turbulator **300** may be constant or vary along the turbulator **300** from the heel end **104** to the toe end **106**. The turbulator **300** may have any pattern similar to the zigzag pattern described above or other patterns that can provide the boundary layer energizing function described above. Such patterns may include various geometric shapes such as square, rectangular, triangular, curved, circular, polygonal or other shapes in discrete or continuous configurations. The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

The turbulator **300** is shown to be a continuous strip in FIG. **4**. However, the turbulator **300** may be formed by a plurality of turbulator segments that are positioned on the crown **110** in different configurations relative to each other such as aligned, offset and/or tandem. For example, the turbulator **300** may include three discrete zigzag strips that are positioned at different distances **301** on the crown **110**. Each of the discrete strips may have similar or different properties, such as similar or different height, width **303**, the distance **305**, the thickness **307**, the angles **309** and/or **311**.

The turbulator **300** may be constructed from any type of material, such as stainless steel, aluminum, titanium, various other metals or metal alloys, composite materials, natural materials such as wood or stone or artificial materials such as plastic. If the turbulator **300** is constructed from metal, it may be formed on the club head **100** or simultaneously with the club head **100** by stamping (i.e., punching using a machine press or a stamping press, blanking, embossing, bending, flanging, or coining, casting), injection molding, forging, machining or a combination thereof, or other processes used for manufacturing metal parts. With injection molding of metal or plastic materials, a one-piece or a multi-piece mold can be constructed which has interconnected cavities corresponding to the above-described parts of the club head **100** and/or the turbulator **300**. Molten metal or plastic material is injected into the mold, which is then cooled. The club head **100** and/or the turbulator **300** is then removed from the mold and may be machined to smooth out irregularities on the surfaces thereof or to remove residual parts. If the turbulator **300** is manufactured separately from the club head **100**, the turbulator **300** can be fixedly or removably attached to the crown **110** with fasteners, adhesive, welding, soldering, or other fastening methods and/or devices. In one example, the turbulator **300** may be formed from a strip of material having an adhesive backing. Accordingly, the turbulator **300** may be attached to the club head **100** at any location on the crown with the adhesive backing.

Referring to FIGS. **9** and **10**, another exemplary turbulator **400** is shown. The turbulator **400** includes a plurality of ridges **401-408** that are positioned downstream of the leading edge **112** and at least partly before the separation region **120**. Each ridge **401-408** may be spaced from the leading edge **112** at the same distance **409** as another ridge or a different distance **409** than another ridge. While FIGS. **9** and **10** may depict a particular number of ridges, the apparatus, methods, and articles of manufacture described herein may include more or less number of ridges. Referring to FIGS. **11-14**, in which examples of only the ridge **404** are shown, each ridge **401-408** has a length **411**, a base width **413**, a height **415** (shown in FIG. **12**) and an angle **417** relative to the leading edge **112** of the club head **100**. Each ridge **401-408** may be spaced apart from an adjacent ridge by a distance **419** (shown in FIGS. **9** and **10**), which is measured from the leading edges **410** of the ridges **401-408** if the ridges are not parallel.

FIG. **11** illustrates an exemplary shape for the ridge **404** and does not in any way limit the shape of the ridges **401-408**. The ridges **401-408** may have any cross-sectional shape. In FIGS. **12-14**, three exemplary cross-sectional shapes for the ridges **401-408** are shown. The length **411** may be substantially greater than the base width **413**. The ridges **401-408** function as vortex generators to energize the boundary layer that forms on the crown **110**, hence moving the separation region **120** further aft on the crown **110**. Thus, each ridge **401-408** functions as a turbulator. The height **415** of each ridge **401-408** may be such that the top **412** (shown in FIG. **12**) of each ridge **402** remains inside the boundary layer. However, any one or more of the ridges may extend above the boundary layer.

The angle **417** for each ridge may be configured so that each ridge **401-408** is oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. In one embodiment, the angle **417** may be between 20° and 70°. In the example of FIGS. **9** and **10**, the turbulator **400** includes four ridges **401-404** on the toe end side of the club head **100** that are oriented generally at an angle **417** of about 60°-70° and parallel to each other. The turbulator **400** also includes four ridges **405-408** that are symmetric with respect to the angle **417** about a centerline **127** of the club head **100** relative to the ridges **401-404**.

Each ridge **401-408** is shown to be a linear. However, each of the ridges **401-408** can be curved, have variable base width **413** along the length **411**, have variable cross-sectional shapes, have variable height **415** along the length **411** and/or the base width **413**, have sharp or blunt leading edges **410** or trailing edges **414**, have sharp or blunt tops **412**, have different surface textures, and/or have other physical variations along the length **411**, the base width **413** and/or the height **415**. The distance **409** may increase for each ridge **401-408** from the heel end **104** to the toe end **106** to approximately correspond with the location of the separation line **120** on the crown **110**. However, as shown in FIGS. **9** and **10**, each ridge **401-408** may be located on the crown **110** at substantially the same distance **409** from the leading edge **112**. Furthermore, each of the ridges **401-408** may be placed anywhere on the crown **110** to provide the boundary layer effects described herein. The location of the ridges may vary depending on the physical characteristics of the club head **100** and the airflow pattern on the crown **110**. Each of the ridges **401-408** may be located along a straight line or a curvilinear line on the crown **110** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **110**. Each ridge **401-408** may have a height **415** that does not exceed 0.5 inches (1.27 cm). In one embodiment, at least one ridge **401-408** may have a height **415** that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). The ridges **401-408** may have a distance **419** that contributes to the delay in airflow separation. The ridges **401-408** may be arranged on the crown **110** in a curvilinear manner based on the location of the separation region **120** of a particular club head **100**. In one embodiment, the ridges **401-408** are located between the face **102** and the apex **111** of the crown **110**. Accordingly, the ridges **402** may be located between the leading edge **112** and the apex **111** of the crown **110**.

Referring to FIG. **10**, each ridge **401-408** trips the air flowing over the ridge to create small eddies or vortices along the length **411** for energizing the boundary layer downstream of the ridge **401-408** in an area **421** (shown only on ridge **404**). Accordingly, the separation region **120** is moved farther aft on the crown **110**. The distance **419** between each ridge **401-408**, length **411**, base width **413**, height **415** and/or angle **417** may be configured so that the areas **421** slightly or greatly overlap, or do not overlap. As shown in the example of FIG. **10**, the distance **419**, the length **411** and the angle **417** of each ridge **401-408** are configured such that the leading edge **410** of each ridge **401-408** is generally aligned along the direction of airflow with the trailing edge **414** of an adjacent ridge **401-408**. Thus, the arrangement of the ridges **401-408** on the crown **110** as shown in of FIGS. **9** and **10** provides overlapping areas **421** of boundary layer turbulence. However, the ridges **401-408** can be configured to have any physical characteristics and spaced apart at any distance **419**. For example, if the ridges have shorter lengths than the length **411** of the ridges **401-408** shown in FIGS. **9** and **10**, the distance **419** can be reduced to ensure overlap of areas **421** downstream of the ridges **401-408**. In another example, if the angles **417** of the ridges **401-408** relative to the club face **100** are different than the angle **417** shown in FIGS. **9** and **10**, the distance **419** or the lengths **411** of the ridges **401-408** can be accordingly modified to ensure that areas **421** overlap downstream of the ridges **401-408**. In yet another example, multiple rows of ridges can be provided on the crown **110** in tandem or offset relative to each other. Thus, any number of ridges with each ridge having any physical characteristic and distance **409** relative to an adjacent ridge can be provided on the crown **110**. For example, in certain application, overlapping of the areas **421** may not be suitable. Accordingly, the ridges **401-408** can be configured to reduce, minimize or prevent overlap of the areas **421**.

Referring to FIG. **10**, the ridges **401-404** are arranged to point toward the centerline **127**, and the ridges **405-408** are also arranged to point toward the centerline **127**. Accordingly, the ridges **401-408** can function as an alignment aid for a player to align the club face **102** with a ball. An individual standing in an address position may visually determine the position of the ball (not shown) relative to the centerline **127** with the aid of the ridges **401-408**.

Referring to FIGS. **15** and **16**, another exemplary turbulator **500** is shown. The turbulator **500** includes a plurality of ridges **501-507** that are positioned downstream of the leading edge **112** and at least partly before the separation region **120**. Each ridge **501-507** may be spaced from the leading edge **112** at the same distance **509** as another ridge or a different distance **509** than another ridge. While FIGS. **15** and **16** may depict a particular number of ridges, the apparatus, methods and articles of manufacture described herein may include more or less number of ridges. Referring to FIGS. **17-20**, in which examples of only the ridge **504** are shown, each ridge **501-507** has a length **511**, a base width **513**, a height **515** (shown in FIG. **18**) and an angle **517** relative to the leading edge **112** of the club head **100**. Each of the ridges **501-507** is spaced apart from an adjacent ridge by a distance **519** (shown in FIGS. **15** and **16**), which is measured from the leading edges **504** of the ridges **501-507** if the ridges are not parallel.

FIG. **17** illustrates an exemplary shape for the ridge **504** and does not in any way limit the shape of the ridges **501-507**. The ridges **501-507** may have any cross-sectional shape. In FIGS. **18-20**, three exemplary cross-sectional shapes for the ridges **501-507** are shown. The length **511** may be substantially greater than the base width **513**. The ridges **501-507** function as vortex generators to energize the boundary layer that forms on the crown **110**, hence moving the separation region **120** further aft on the crown **110**. Thus, each ridge **501-507** functions as a turbulator. The height **515** of each ridge **501-507** may be such that the top **512** (shown in FIG. **18**) of each ridge **501-507** remains inside the boundary layer. However, any one or more of the ridges may extend above the boundary layer.

The angle **517** for each ridge may be configured so that each ridge **501-507** is oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. In one embodiment, the angle **517** may be between 20° and 70°. In the example of FIGS. **15** and **16**, the turbulator **500** includes seven ridges **501-507** that are oriented generally at an angle **517** of about 60°-70° and parallel to each other.

Each ridge **501-507** is shown to be a linear. However, each of the ridges **501-507** can be curved, have variable base width **513** along the length **511**, have variable cross-sectional shapes, have variable height **515** along the length **511** and/or the base width **513**, have sharp or blunt leading edges **510** or trailing edges **514**, have sharp or blunt tops **512**, have different surface textures, and/or have other physical variations along the length **511**, the base width **513** and/or the height **515**. The distance **509** may increase for each ridge **501-507** from the heel end **104** to the toe end **106** to approximately correspond with the location of the separation line **120** on the crown **110**. However, as shown in FIGS. **15** and **16**, each ridge **501-507** may be located at substantially the same distance **509** from the leading edge **112**. Furthermore, each of the ridges **501-507** may be placed anywhere on the crown **110** to provide the boundary layer effects described herein. The location of the ridges may vary depending on the physical characteristics of the club head **100** and the airflow pattern on the crown **110**. Each of the ridges **501-507** may be located along a straight line or a curvilinear line on the crown **110** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **110**. Each ridge **501-507** may have a height **515** that does not exceed 0.5 inches (1.27 cm). In one embodiment, at least one ridge **501-507** may have a height **515** that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). The ridges **501-507** may have a distance **519** that contributes to the delay in airflow separation. The ridges **501-507** may be arranged on the crown **110** in a curvilinear manner based on the location of the separation region **120** of a particular club head **100**. In one embodiment, the ridges **501-507** are located prior to the apex **111** of the crown **110**. Accordingly, the ridges **501-507** may be located between the leading edge **112** and the apex **111** of the crown **110**.

Referring to FIG. **16**, each ridge **501-507** trips the air flowing over the ridge to create small eddies or vortices along the length **511** for energizing the boundary layer downstream of the ridge **501-507** in an area **521** (shown only on ridge **504**). Accordingly, the separation region **120** is moved farther aft on the crown **110**. The distance **519** between each ridge **501-507**, length **511**, base width **513**, height **515** and/or angle **517** may be configured so that the areas **521** slightly or greatly overlap, or do not overlap. As shown in the example of FIG. **16**, the distance **519**, the length **511** and the angle **517** of each ridge **501-507** are configured such that the leading edge **510** of each ridge **501-507** is generally aligned along the direction of airflow with the trailing edge **514** of an adjacent ridge **501-507**. Thus, the arrangement of the ridges **501-507** on the crown **110** as shown in of FIGS. **15** and **16** provides overlapping areas **521** of boundary layer turbulence. However, the ridges **501-507** can be configured to have any physical characteristics and spaced apart at any distance **519**. For example, if the ridges have shorter lengths than the length **511** of the ridges **501-507** shown in FIGS. **15** and **16**, the distance **519** can be reduced to ensure overlap of areas **521** downstream of the ridges **501-507**. In another example, if the angles **517** of the ridges **501-507** relative to the club face **100** are different than the angle **517** shown in FIGS. **15** and **16**, the distance **519** or the lengths **511** of the ridges **501-507** can be accordingly modified to ensure that areas **521** overlap downstream of the ridges **501-507**. In yet another example, multiple rows of ridges can be provided on the crown **110** in tandem or offset relative to each other. Thus, any number of ridges with each ridge having any physical characteristic and distance **509** relative to an adjacent ridge can be provided on the crown **110**. For example, in certain application, overlapping of the areas **521** may not be suitable. Accordingly, the ridges **501-507** can be configured to reduce minimize or prevent overlap of the areas **521**.

Referring to FIGS. **21** and **22**, another exemplary turbulator **600** is shown. The turbulator **600** includes a plurality of ridges **601-608** that are positioned downstream of the leading edge **112** and at least partly before the separation region **120**. Each ridge **601-608** may be spaced from the leading edge **112** at the same distance **609** as another ridge or at a different distance **609** than another ridge. While FIGS. **21** and **22** may depict a particular number of ridges, the apparatus, methods, and articles of manufacture described herein may include more or less number of ridges. Referring to FIGS. **22-26**, in which examples of only the ridge **604** are shown, each ridge **601-608** has a length **611**, a base width **613**, a height **615** (shown in FIG. **24**) and an angle **617** relative to leading edge **112** of the club head **100**. Each of the ridges **601-608** is spaced apart from an adjacent ridge by either a first peak-to-peak distance **623** or a second peak-to-peak distance **625** (shown in FIGS. **21** and **22**), where **623** and **625** are measured from the leading edges **604** of adjacent ridges **601-608**.

FIG. **23** illustrates an exemplary shape for a ridge **604** and does not in any way limit the shape of the ridges **601-608**. The ridges **601-608** may have any cross-sectional shape. In FIGS. **24-26**, three exemplary cross-sectional shapes for the ridges **601-608** are shown. The length **611** may be substantially greater than the base width **613**. The ridges **601-608** function as vortex generators to energize the boundary layer forming on the crown **110**, hence moving the separation region **120** further aft on the crown **110**. Thus, each ridge **601-608** functions as a turbulator. The height **615** of each ridge **601-608** may be such that the top **612** (shown in FIG. **24**) of each ridge **601-608** remains inside the boundary layer.

The angle **617** for each ridge may be configured so that each ridge **601-608** is oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. In one embodiment, the angle **617** may be between 20° and 70° in the absolute value. In the example of FIGS. **21** and **22**, the turbulator **600** includes eight ridges **601-608**. The ridges **601**, **603**, **605** and **607** are oriented generally at an angle **617** of about −60° to −70° (see FIG. **17** for a positive angle of a ridge) and parallel to each other. The turbulator **600** also includes four ridges **602**, **604**, **606** and **608** that are oriented at an angle **617** of about 60° to 70°. Thus, each pair of adjacent ridges **601** and **602**; **603** and **604**; **605** and **606**; and **606** and **608** is configured to resemble a V shape, a triangle or a similar shape.

The ridges **604** and **605** symmetrically straddle the centerline **127** and generally point toward the centerline **127**. Accordingly, the ridges **604** and **605** can function as an alignment device to assist a player in generally aligning the ball with the centerline **127**.

Each ridge **601-608** is shown to be a linear. However, each of the ridges **601-608** can be curved, have variable base width **613** along the length **611**, have variable cross-sectional shapes, have variable height **615** along the length **611** and/or the base width **613**, have sharp or blunt leading edges **610** or trailing edges **614**, have sharp or blunt tops **612**, have different surface textures, and/or have other physical variations along the length **611**, the base width **613** and/or the height **615**. The distance **609** may increase for each ridge **601-608** from the heel end **104** to the toe end **106** to approximately correspond with the location of the separation line **120** on the crown **110**. However, as shown in FIGS. **21** and **22**, each ridge **601-608** may be located at substantially the same distance **609** from the leading edge **112**. Furthermore, each of the ridges **601-608** may be placed anywhere on the crown **110** to provide the boundary layer effects described herein. The location of the ridges may vary depending on the physical characteristics of the club head **100** and the airflow pattern on the crown **110**. Each of the ridges **601-608** may be located along a straight line or a curvilinear line on the crown **110** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **110**. Each ridge **601-608** may have a height **615** that does not exceed 0.5 inches (1.27 cm). In one embodiment, at least one ridge **601-608** may have a height **615** that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). The ridges **601-608** may have a distance **623** or **625** that contributes to the delay in airflow separation. The ridges **601-608** may be arranged on the crown **110** in a curvilinear manner based on the location of the separation region **120** of a particular club head **100**. In one embodiment, the ridges **601-608** are located prior to the apex **111** of the crown **110** (highest point on the crown). Accordingly, the ridges **601-608** may be located between the leading edge **112** and the apex **111** of the crown **110**.

Referring to FIG. **22**, each ridge **601-608** trips the air flowing over the ridge to create small eddies or vortices along the length **611** for energizing the boundary layer downstream of the ridge **601-608** in an area **621** (shown only on ridge **604**). Accordingly, the separation region **120** is moved farther aft on the crown **110**. The distance **623** or **625** between each ridge **601-608**, length **611**, base width **613**, height **615** and/or angle **617** may be configured so that the areas **621** slightly or greatly overlap, or do not overlap. The arrangement of the ridges **601-608** on the crown **110** as shown in of FIGS. **21** and **22** provides overlapping areas **621** of boundary layer turbulence. However, the ridges **601-608** can be configured to have any physical characteristics and spaced apart at any distance **623** or **625**. For example, if the ridges have shorter lengths than the length **611** of the ridges **601-608** shown in FIGS. **21** and **22**, the distance **623** or **625** can be reduced to ensure overlap of areas **621** downstream of the ridges **601-608**. In another example, if the angles **617** of the ridges **601-608** relative to the club face **100** are different than the angle **617** shown in FIGS. **21** and **22**, the distance **623** or **625** or the lengths **611** of the ridges **601-608** can be accordingly modified to ensure that areas **621** overlap downstream of the ridges **601-608**. In yet another example, multiple rows of ridges can be provided on the crown **110** in tandem or offset relative to each other. Thus, any number of ridges with each ridge having any physical characteristic and distance **609** relative to an adjacent ridge can be provided on the crown **110**. For example, in certain application, overlapping of the areas **621** may not be suitable. Accordingly, the ridges **601-608** can be configured to reduce minimize or prevent overlap of the areas **621**.

The turbulator **400**, **500** or **600** may be constructed from any type of material, such as stainless steel, aluminum, titanium, various other metals or metal alloys, composite materials, natural materials such as wood or stone or artificial materials such as plastic. If the turbulator **400**, **500** or **600** is constructed from metal, it may be formed on the club head **100** or simultaneously with the club head **100** by stamping (i.e., punching using a machine press or a stamping press, blanking, embossing, bending, flanging, or coining, casting), injection molding, forging, machining or a combination thereof, or other processes used for manufacturing metal parts. With injection molding of metal or plastic materials, a one-piece or a multi-piece mold can be constructed which has interconnected cavities corresponding to the above-described parts of the club head **100** and/or the turbulator **400**, **500** or **600**. Molten metal or plastic material is injected into the mold, which is then cooled. The club head **100** and/or the turbulator **400**, **500** or **600** is then removed from the mold and may be machined to smooth out irregularities on the surfaces thereof or to remove residual parts. If the turbulator **400**, **500** or **600** is manufactured separate from the club head **100**, the turbulator **400**, **500** or **600** can be fixedly or removably attached to the crown **110** with fasteners, adhesive, welding, soldering, or other fastening methods and/or devices. In one example, the turbulator **400**, **500** or **600** may be formed from metallic material. The turbulator **400**, **500** or **600** can then be attached to the crown **110** with an adhesive. In another example, the turbulator **400** may include an elongated projection that slides into a correspondingly sized slot on the crown **110** to removably attached the turbulator **400**, **500** or **600** to the crown **110**.

Thus, the turbulators **400**, **500** or **600** may include removable connection mechanisms so that each turbulator **400**, **500** or **600** can be selectively connected to or removed from the club head **100**. The turbulators on the crown **110** are described above to be defined by ridges. However, any one or more of the turbulators may be defined by grooves formed in the crown **110**. The turbulators may be formed by cutting grooves in the crown **110** by various methods such machining, laser cutting, or the like.

According to one example shown in FIG. **27**, a method **700** of manufacturing a golf club head having turbulators according to various embodiments includes at **702** providing a golf club having a club head, and at **704**, attaching one or more turbulators on a crown of the club head. According to another example shown in FIG. **28**, a method **800** of manufacturing a golf club head having turbulators according to various embodiments includes at **802** providing a mold having cavities corresponding to a golf club head and one or more turbulators, and at **804**, forming the club head and the turbulators with the mold.

FIG. **29** shows a schematic view based on actual airflow visualization experiments of airflow over the club head **100** without turbulators, and FIG. **30** shows a schematic view based on actual airflow visualization experiments of airflow over the same club head with the turbulators **400**. In FIG. **29**, the streamlines representing airflow approach the club had **100** and are diverted over the club face toward the leading edge. The streamlines traverse over the leading edge **112** and flow over the crown **110**. However, the airflow becomes detached from the crown **110** at the separation region **120**, and creates a turbulent wake **122** over a substantial section of the crown **110**. This turbulent wake **122** increases the drag thereby reducing the speed of the club head **100**. Referring to FIG. **30**, the ridges **401-408** are positioned downstream of the leading edge **112** and upstream of the separation region **120** of FIG. **29**. Accordingly, the flow remains attached on a substantial portion of the crown **110** as is shown by the streamlines in FIG. **30**. Therefore, the separation region **120** is moved farther aft on the crown **110**.

As described above, any of the physical characteristics of the turbulators **400**, **500** or **600**; the locations thereof on the crown; and/or the orientations thereof relative to any part of the crown, the centerline **127** and/or the leading edge **112** may be configured to provide a particular boundary layer effect. According to one embodiment, the turbulators may be located a distance Q from the leading edge **112** according to the following relation:

$$Q>0.05DA$$

where DA is the distance from the leading edge **112** to the apex **111** of the crown (i.e., the highest point on the crown). According to another embodiment, the angle γ, which is the angle of each ridge relative to the leading edge **112** may follow the relation:

$$\gamma>\text{Loft}$$

where Loft is the loft angle of the club head **100**. According to another embodiment, the distance P, which is the distance between each ridge, may follow the relation:

$$2L\cos(\gamma)>P>0.8L\cos(\gamma)$$

where L is the length of a ridge.

Tables 1 and 2 show experimental results for a golf club head **100** without any turbulators, with the turbulator **300**, and with turbulators **400**. Table 1 shows measured values of aerodynamic drag expressed in lbs for different orientation angles of the club head **100**. The speed of the club head **100** is directly affected by the orientation angle. An increase in orientation angle results in an increase in the speed of the club head **100**.

TABLE 1

Drag Force (lbs) vs. Orientation Angle (degrees)			
Angle (in degrees)	Without turbulators	Turbulator 300	Turbulator 400
90	2.01496256	1.507344	1.495429
60	1.30344225	1.300062	1.293326
30	0.88754571	0.905306	0.898112
0	0.22323528	0.227507	0.235375

TABLE 2

Lift Force (lbs) vs. Orientation Angle (degrees)			
Angle (in degrees)	Without turbulators	Turbulator 300	Turbulator 400
90	−0.3884699	0.061148	0.092846
60	0.27763904	0.343283	0.189739
30	0.6006895	0.608558	0.560674
0	0.20772346	0.205925	0.225259

As shown in Table 1, when the club head **100** has an orientation angle of greater than 60°, the aerodynamic drag force on the club head **100** is reduced for the club head **100** having the turbulator **300** or the turbulators **400**. The reduction in drag is much greater for an orientation angle of 90°. Referring to FIG. **31**, which is a graphical representation of the data in Table 1, the noted reduction in drag for orientation angles of greater than 60° is visually shown. Furthermore, the turbulator **400** (including one or more ridges **401-408**) is shown to reduce the drag force on the club head **100** more than the turbulator **300**.

Table 2 shows measured values of lift expressed in lbs for different orientation angles of the club head. When the club head **100** has an orientation angle of greater than 60°, the lift generated by the club head does not drop as sharply for the club head **100** having the turbulator **300** or the turbulators **400** as compared to the club head **100** without any turbulators. Referring to FIG. **32**, which is a graphical representation of the data in Table 2, the noted drop in lift for the club head **100** without any turbulators is visually shown. The noted drop in lift is due to the higher pressure differential caused by the earlier boundary layer separation on the crown for the club head **100** without any turbulators as compared to the club head **100** having turbulator **300** or turbulators **400**. Thus, Tables 1 and 2 and FIGS. **31** and **32** illustrate the adverse effects of early boundary layer separation on the crown for a golf club head without any turbulators and the effects of delaying the boundary layer separation on drag forces exerted on a golf club head.

FIGS. **33** and **34** graphically show measured ball speed and club head speed for a golf club head without any turbulators and a golf club head having the turbulators **400**. FIG. **33** shows that ball speed is higher when the golf club head includes the turbulators **400**. This increase in ball speed is due to the higher club head speed as shown in FIG. **34** due to the turbulators **400** delaying boundary layer separation on the crown, thereby reducing drag forces on the club head.

Referring to FIGS. **35-38**, another exemplary golf club head **1000** is shown, which includes a face **1002** that extends horizontally from a heel end **1004** to a toe end **1006** and vertically from a sole **1008** to a crown **1010**. The heel end

1004 and the toe end 1006 extend from the face 1002 to the rear 1009 of the club head 1000. A transition region between the face 1002 and the crown 1010 defines an upper leading edge 1012 and a transition region between the face 1002 and the sole defines a lower leading edge 1013. The club head 1000 also include a hosel 1014 for receiving a shaft (not shown). The club head 1000 is shown to be a wood-type club head. However, the present disclosure is not limited to wood-type club heads and applies to any type of golf club head (e.g., a driver-type club head, a fairway wood-type club head, a hybrid-type club head, an iron-type club head, a wedge-type club head, or a putter-type club head).

Club head 1000 includes a plurality of turbulators 1201-1204 and 1301-1304 on the sole 1008, which may be generally referred to herein as turbulators 1200 and 1300, respectively. The turbulators 1200 and 1300 energize the boundary layer on the sole 1008 during the downswing, the impact position, and the follow through phases of the golf swing. During the initial part of the downswing, the air that is upstream of the club head 1000 flows generally over the heel 1004 and onto the sole 1008 and the crown 1010. During the intermediate part of the downswing, the air flows generally over the transition area between the heel 1004 and the face 1002 and onto the sole 1008 and the crown 1010. During the final part of the downswing just prior to the impact position, the air flows generally over the face 1002 and onto the sole 1008 and the crown 1010. Arrow 1210 of FIGS. 36 and 38 represents one exemplary direction of airflow during the downswing part of the golf swing. The air flowing over the sole 1008 forms a boundary layer on the sole. The turbulators 1200 energize the boundary layer to delay detachment of the flow downstream of the turbulators 1200. Accordingly, the drag on the club head 1000 is reduced thereby increasing club speed during the downswing.

After the face 1002 strikes the ball in the impact position, the club head 1000 is rotated during the follow through. The air that is upstream of the club head 1000 flows generally over the face 1002 and onto the sole 1008 and the crown 1010 during the initial part of the follow through. During the intermediate part of the follow through, the air flows generally over the transition area between the toe 1006 and the face 1002 and onto the sole 1008 and the crown 1010. During the final part of the follow through, the air may flow generally over the toe 1006 and onto the sole 1008 and the crown 1010. As shown in FIGS. 36 and 38, arrow 1310 represents one exemplary direction of airflow during the follow through part of the golf swing.

FIG. 37 shows x and y coordinate axes for describing the dimensions, locations on the sole 1008, and orientations relative to the face 1002 of the turbulators 1200 and 1300. The x and y coordinate axes have an origin 1240 (i.e., x=0, y=0), which may define a center point of the face 1002. Accordingly, the y axis may define a center line for the club head 1000. As described in detail below, the location of each turbulator 1200 and 1300 on the sole 1009 can be expressed by an x-location and a y-location. Furthermore, the orientations of the turbulators 1200 and 1300 can be expressed relative to the x axis by an angle 1242.

The turbulators 1201-1204 may be defined by grooves that generally extend from near the heel end 1004 in a direction toward the toe end 1006. Each turbulator 1201-1204 has a first end 1211-1214 and a second end 1215-1218, respectively. The first ends 1211-1214 are located near the heel end 1004 and may generally follow the contour of the heel end 1004. Accordingly, the first ends 1211-1214 of the turbulators 1201-1204 may have approximately the same distance from

the heel end 1004. However, the first ends 1211-1214 may be located anywhere on the sole 1008 to delay airflow separation on the sole 1008.

The turbulators 1201-1204 may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. Depending on the position of the airflow separation region during the downswing, which is shown by example with line 1250 in FIG. 38, the configurations of the turbulators 1200 can be varied to energize the airflow upstream of the separation region 1250. For example, the turbulators 1201-1204 progressively increase in length in a direction from the face 1002 to the rear 1009. Accordingly, the second ends 1215-1218 are progressively nearer to the y axis. Thus, the progressive length increase of the turbulators 1201-1204 may follow the contour of the separation region 1250 so as to provide detached flow on the sole 1008 downstream of the turbulators 1201-1204. Similarly, the depth, the width and/or the angle 1242 of each turbulator 1201-1204 may be varied to provide a particular flow pattern. As shown in FIG. 37, the angle 1242 progressively increases in a direction from the face 1002 to the rear 1009. The angle 1242 for each turbulator 1201-1204 may correspond with a particular rotational position of the club head 1000 during the downswing. Accordingly, by varying the angle 1242 in the direction from the face 1002 to the rear 1009, the turbulators 1201-1204 may energize the flow upstream of the separation region S1 for generally all rotation angles of the club head 1000 during the downswing. The angle 1242 may be measured between any reference line on a turbulator and the x or y axis. In the disclosure, the angle 1242 is measured as the angle between the x-axis and a line connecting the ends of a turbulator.

The grooves defining the turbulators 1201-1204 may be wider at the first ends 1211-1214 and narrower at the second ends 1215-1218, respectively. The depth of the grooves may also gradually decrease from the first ends 1211-1214 to the second ends 1215-1218, respectively. The grooves may be formed in any shape on the sole 1008. For example, the grooves can be narrow at the first ends 1211-1214 and the second ends 1215-1218 and then gradually or abruptly widen toward the centers of the grooves 1201-1204. In contrast, the grooves can be wider at the first ends 1211-1214 and the second ends 1215-1218 and then gradually or abruptly narrow toward the centers of the grooves 1201-1204. The depth of the grooves may also vary in any manner, such as according to the variation in width of the grooves.

The width, length, depth, location (i.e., x and y location), angle 1242, and the shapes of the grooves that define the turbulators 1200 can be varied from the face 1002 to the rear 1009 to provide a particular flow pattern for generally all rotation angles of the club head 1000 during the downswing. Furthermore, the number of turbulators 1200 can also be varied to provide a particular flow pattern on the sole 1008. For example, five, six or more turbulators 1200 can be provided on the sole 1008. The turbulators 1200 may be located on the sole 1008 adjacent to each in a direction from the face 1002 to the rear 1009, and/or may be in tandem.

Table 3 below shows exemplary configurations for the turbulators 1201-1204. The x and y locations refer to the x and y locations of the second ends 1215-1218. All of dimensions in Table 3 are expressed in inches. Furthermore, the depth and width of the grooves defining the turbulators 1201-1204 are measured at the first ends 1211-1214 of the turbulators 1201-1204, respectively. Table 3 represents only an example of the turbulators 1201-1204 and in no way limits the properties of the turbulators 1200.

TABLE 3

Turbulator	Depth	Length	Width	Location - X	Location - Y	Angle 1242°
1201	0.063	1.14	0.11	−1.31	1.28	2.95
1202	0.065	1.28	0.11	−1.01	1.67	7.97
1203	0.066	1.41	0.11	−0.68	2.05	16.98
1204	0.067	1.52	0.11	−0.35	2.39	30

The turbulators **1301-1304** may be defined by grooves that generally extend from near a portion of the face that is close to the toe end **1006** toward the rear **1009**. The grooves may also extend generally from near a transition area between the face **1002** and the toe end **1006** toward the rear **1009**. Additionally, the grooves may extend from near the toe end **1006** toward the rear **1009**. Each turbulator **1301-1304** has a first end **1311-1314** and a second end **1315-1318**, respectively. The first ends **1311-1314** are located near the face **1002** or the toe end **1006** and may either extend in a direction from the face **1002** toward the rear **1009** or generally follow the contour of the toe end **1006**. However, the first ends **1311-1314** may be located anywhere on the sole **1008** to delay airflow separation on the sole **1008**.

The turbulators **1301-1304** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. Depending on the position of the airflow separation region, which is shown by example with line **1350** in FIG. **38**, the dimensional characteristics of the turbulators **1300** can be varied to energize the airflow upstream of the separation region **1350**. For example, the turbulators **1301-1304** progressively increase in length in a direction from the face **1002** toward the toe end **1006** and from the toe end **1006** toward the rear **1009**. Accordingly, the second ends **1315-1318** are progressively farther from the x axis and the y-axis. The progressive length increase of the turbulators **1301-1304** may follow the contour of the separation region **1350** to provide attached airflow downstream of the turbulators **1301-1304**. Similarly, the depth, the width and/or the angle **1242** of each turbulator **1301-1304** may vary to provide a particular flow pattern. As shown in FIG. **37**, the angle **1242** progressively decreases in a direction from the face **1002** toward the toe end **1006** and from the toe end toward the rear **1009**. The angle **1242** for each turbulator **1301-1304** may correspond with a particular rotational position of the club head **1000** during follow through. Accordingly, by varying the angle **1242** in the direction from the face **1002** toward the toe end **1006** and from the toe end **1006** toward the rear **1009**, the turbulators **1301-1304** may energize the flow upstream of the separation region **1350** for generally all rotation angles of the club head **100** during follow through. Further, each of the turbulators **1301-1304** may have a curvature that generally corresponds to the curvature of the toe end **1006**, and may represent the general direction of airflow over the sole **1008** during impact position and follow through. The angle **1242** may be measured between any reference line on a turbulator and the x or y axis. In the disclosure, the angle **1242** is measured as the angle between the x-axis and a line connecting the ends of a turbulator.

The grooves defining the turbulators **1301-1304** may be wider at the first ends **1311-1314** and narrower at the second ends **1315-1318**, respectively. The depth of the grooves may also gradually decrease from the first ends **1311-1314** to the second ends **1315-1318**, respectively. The grooves may be formed in any shape on the sole **1008**. For example, the grooves can be narrow at the first ends **1311-1314** and the second ends **1315-1318** and then gradually or abruptly widen toward the centers of the grooves **1301-1304**. In contrast, the grooves can be wider at the first ends **1311-1314** and the second ends **1315-1318** and then gradually or abruptly narrow toward the centers of the grooves **1301-1304**. The depth of the grooves may also vary in any manner, such as according to the variation in width of the grooves.

The width, length, depth, location (i.e., x and y location), angle **1242**, and the shapes of the grooves defining the turbulators **1300** can be varied from the face **1002** toward the toe end **1006** and from the toe end **1006** toward the rear **1009** to provide a particular flow pattern for generally all rotation angles of the club head **1000** during follow through. Furthermore, the number of turbulators **1300** can also be varied to provide a particular flow pattern on the sole **1008**. For example, five, six or more turbulators **1300** can be provided on the sole **1008**. The turbulators **1300** may be located on the sole **1008** adjacent to each other and/or in tandem.

Table 4 below shows exemplary configurations for the turbulators **1301-1304**. The x and y locations refer to the x and y locations of the second ends **1315-1318**. All of the dimensions shown in Table 4 are expressed in inches. Furthermore, the depth and width of the grooves defining the turbulators **1301-1304** are measured at the first ends **1311-1314** of the turbulators **1301-1304**, respectively. Table 3 is only an exemplary configuration of the grooves **1301-1304** and in no way limits the properties of the turbulators **1300**.

TABLE 4

Turbulator	Depth	Length	Width	Location - X	Location - Y	Angle 1242°
1301	0.05	0.80	0.12	1.60	1.60	90.09
1302	0.06	0.97	0.12	1.94	1.93	86.56
1303	0.07	1.09	0.12	2.24	2.27	83.03
1304	0.08	2.29	0.12	1.91	3.54	69.02

The turbulator **1200** and **1300** are described above to be defined by grooves in the sole **1008**. Accordingly, the turbulators **1200** and **1300** may be formed on the golf club **1000** by cutting the grooves into the sole **1008** of the golf club **1000** by various methods such machining, laser cutting, or the like. Alternatively, any one or more of the turbulators **1200** and/or the turbulators **1300** may be defined by ridges or projections on the sole **1008**. Such grooves or ridges may be formed simultaneously with the club head **1000** by stamping (i.e., punching using a machine press or a stamping press, blanking, embossing, bending, flanging, or coining, casting), injection molding, forging, machining or a combination thereof, or other processes used for manufacturing metal parts. With injection molding of metal or plastic materials, a one-piece or a multi-piece mold can be constructed which has interconnected cavities corresponding to the above-described parts of the club head **1000** and/or the turbulators **1200** and **1300**. Molten metal or plastic material is injected into the mold, which is then cooled. The club head **1000** and/or the turbulators **1200** and **1300** is then removed from the mold and may be machined to smooth out irregularities on the surfaces thereof or to remove residual parts. If the turbulators **1200** and **1300** are in the form of ridges and are to be manufactured separately from the club head **1000**, the turbulator **300** can be fixedly or removably attached to the sole **1008** with fasteners, adhesive, welding, soldering, or other fastening methods and/or devices. In one example, the turbulator **1200** or **1300** may be formed from a strip of material having an adhesive backing. Accordingly, the turbulators **1200** and **1300** may be attached to the club head **1000** at any location on the sole **1008** with the adhesive backing.

FIG. **39** shows grooves **1401-1404** and **1451-1454** on the sole **1008** of the golf club **1000** according to another embodiment. The grooves **1401-1404** and **1451-1454** may be generally referred to herein as grooves **1400** and **1500**, respectively. The grooves **1401-1404** may be located between the centerline **1413** and the heel end **1006** and generally extend from the heel end **1004** toward the face **1002** or toward a region between the toe end **1006** and the face **1002**. The centerline **1413** may be defined by a line that extends from a center portion of the face **1002** to the rear **1009** and may generally define a center line of the golf club head. The grooves **1451-1454** may generally extend from near a portion of the sole **1008** that is close to the toe end **1006** toward the rear **1009**. The grooves **1451-1454** may also or alternatively extend from near a region between the face **1002** and the toe end **1006** toward the rear **1009**. The grooves **1401-1404** and **1451-1454** are formed on the surface of the sole **1008** and may appear as depressions on the surface of the sole **1008**.

The grooves **1401-1404** may be arranged adjacent to each other on the sole **1008** along the contour of the heel end **1004**. The grooves **1401-1404** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. For example, the grooves **1401-1404** are shown in FIG. **39** to progressively increase in length in a direction from the face **1002** to the rear **1009**. Each of the grooves **1451-1454** may either extend in a direction from the face **1002** toward the rear **1009** and/or generally follow the contour of the toe end **1006**. The grooves **1451-1454** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. For example, the grooves **1451-1454** may progressively decrease in length in a direction from the toe end **1006** to the heel end **1004**. The grooves **1400** and **1500** may be constructed with similar methods as the disclosed methods for constructing the turbulators **1200** and **1300**. Accordingly, a detailed description of methods of manufacturing the grooves **1400** and **1500** is not described for brevity. The grooves **1401-1404** and **1451-1454** may have any shape and/or configuration and are not limited in configuration to the grooves described herein.

Increasing the size of a golf club head may provide a larger golf club face for better face response, allow the center of gravity of the golf club to be lowered and/or moved rearward, and/or allow the moment of inertia of the golf club to be optimized. However, the size of a golf club head may be limited to a particular size. For example, a golf governing body may limit a head of a driver-type golf club to a certain volume, such as 460 cubic centimeters. To increase the size of a golf club head without exceeding a certain volume limitation, the depth, width, length and other characteristics of the grooves **1401-1404** and **1451-1454** may be determined so that a reduction in volume of the club head as a result of providing the grooves is used to increase the size of the club head. For example, if the volume of a golf club head is limited to 460 cubic centimeters, the grooves **1401-1404** and **1451-1454** may be formed to provide a volume reduction of about 20 cubic centimeters in the golf club head. In other words, the volume defined by the grooves **1401-1404** and **1451-1454** may be about 20 cubic centimeters. Accordingly, the golf club head may be constructed to be as large as a golf club head having a volume of 480 cubic centimeters, yet have a volume of 460 cubic centimeters by having the grooves **1401-1404** and **1451-1505**. Thus, the grooves **1401-1404** and **1451-1454**, or any grooves formed on a golf club head as described herein, allow a golf club head to be made larger without exceeding a certain volume limitation. According to another example, a golf club head may be constructed having a volume of 478 cubic centimeters. By forming the grooves **1401-1404** to define a volume of 4 cubic centimeters and the grooves **1451-1454** to define a volume of 6 cubic centimeters, the volume of the golf club head may be reduced to 468 cubic centimeters and yet have generally the same size as a club head having a volume of 478 cubic centimeters.

FIG. **40** shows an enlarged view of the groove **1453** to illustrate an exemplary shape of the grooves **1401-1404** and **1451-1454**. However, the grooves **1410-1404** and **1451-1454** may be in any configuration. Each groove **1401-1404** and **1451-1454** is defined by an end wall **1460**, two side walls **1462** and a bottom **1464**. The side walls **1462** diminish in height from the end wall **1460** to a groove tail portion **1466**, at which the bottom **1464** transitions to the surface of the sole **1008** of the golf club. Accordingly, the depth of each groove increases from the groove tail portion **1466** to the end wall **1460**. The bottom **1464** may have the same width along the length of the groove as shown in the example of FIG. **39**. The side walls **1462** may be perpendicular to the bottom **1464** and the end wall **1460**. Alternatively, the side walls **1462** may be non-perpendicular relative to the bottom **1464** and the end wall **1460**. The side walls **1462** may have similar or dissimilar lengths or depths. The end wall **1460**, the side walls **1462** and the bottom **1464** may have any configuration so that a certain groove shape defining a certain volume is provided.

The grooves **1401-1404** and **1451-1454** may increase the rigidity or stiffness of the sole **1008** of a golf club head by functioning as reinforcing ribs. The increased rigidity may be provided by the shape of the grooves as defined by the angled connections between the end wall **1460**, the side walls **1462** and the bottom **1464**. The increased rigidity of the sole **1008** of a golf club head may prevent denting of the golf club head due to impact with a golf ball, possible impact with the ground, possible impact with an object other than a golf ball, and/or repeated use. Furthermore, the increased rigidity of the sole **1008** may allow the sole **1008** of a golf club head to be constructed with a reduced thickness to reduce the weight of a golf club head without affecting the structural integrity of the golf club head. Changing the thickness of the sole **1008** of a golf club may also affect the sound characteristics of the golf club. For example, the thickness of the sole **1008** may directly affect the frequency and/or the amplitude of the sound wave produced by a golf club head when impacting a ball. A thinner sole **1008** may produce a lower frequency sound, i.e., lower pitch, while a thicker sole **1008** may produce a higher frequency sound, i.e., higher pitch. Accordingly, by providing the grooves **1401-1404**, **1451-1454** and/or any of the disclosed grooves on a golf club head, the thickness of the sole **1008** or other portions of the golf club head may be determined so that a certain sound is produced by the golf club head when impacting a golf ball.

The grooves **1401-1404** and/or the grooves **1451-1454** may be configured to provide certain sound characteristics for a golf club head. Changing the width, length and/or depth profile characteristics of one or more of the grooves and/or changing the distance between each groove may change the frequency and/or amplitude of the sound waves produced when the golf club head strikes a golf ball. For example, a plurality of deep and/or wide grooves may produce a lower frequency sound while a plurality of shallow and/or narrow grooves may produce a high frequency sound. In another example, placing the grooves closer together may produce a higher frequency sound while placing the grooves farther apart may produce lower frequency sound. Accordingly, the grooves **1401-1404**, **1451-1454** and/or any of the disclosed grooves on a golf club head can be configured so that a certain sound is produced by the golf club head when impacting a golf ball.

FIG. **41** shows grooves **1501-1503** and **1551-1554** on the sole **1008** of the golf club **1001** according to another embodiment. The grooves **1501-1503** may be located between the centerline **1513** and the heel end **1006** and generally extend from the heel end **1004** toward the face **1002** or toward a region between the toe end **1006** and the face **1002**. The centerline **1513** may be defined by a line that extends from a center portion of the face **1002** to the rear **1009** and may generally define a center line of the golf club head. The grooves **1551-1554** may generally extend from near a portion of the sole **1008** that is close to the toe end **1006** toward the rear **1009**. The grooves **1551-1554** may also or alternatively extend from near a region between the face **1002** and the toe end **1006** toward the rear **1009**. The grooves **1501-1503** and **1551-1554** are formed on the surface of the sole **1008** and may appear as depressions on the surface of the sole **1008**.

The grooves **1501-1503** may be arranged adjacent to each other on the sole **1008** along the contour of the heel end **1004**. The grooves **1501-1503** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. For example, the grooves **1501-1503** are shown in FIG. **41** to progressively increase in length in a direction from the face **1002** to the rear **1009**. Each of the grooves **1551-1554** may either extend in a direction from the face **1002** toward the rear **1009** and/or generally follow the contour of the toe end **1006**. The grooves **1551-1554** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. For example, the grooves **1551-1554** may progressively decrease in length in a direction from the toe end **1006** to the heel end **1004**. The grooves **1501-1503** and **1551-1554** may be constructed with similar methods as the disclosed methods for constructing the turbulators **1200** and **1300**. Accordingly, a detailed description of methods of manufacturing the grooves **1501-1503** and **1551-1554** is not described for brevity. The grooves **1501-1503** and **1551-1554** may have any shape and/or configuration and are not limited in configuration to the grooves described herein.

Increasing the size of a golf club head may provide a larger golf club face for better face response, allow the center of gravity of the golf club to be lowered and/or moved rearward, and/or allow the moment of inertia of the golf club to be optimized. However, the size of a golf club head may be limited to a particular size. For example, a golf governing body may limit a head of a driver-type golf club to a certain volume, such as 460 cubic centimeters. To increase the size of a golf club head without exceeding a certain volume limitation, the depth, width, length and other characteristics of the grooves **1501-1503** and **1551-1554** may be determined so that a reduction in volume of the club head as a result of providing the grooves is used to increase the size of the club head. For example, if the volume of a golf club head is limited to 460 cubic centimeters, the grooves **1501-1503** and **1551-1554** may be formed to provide a volume reduction of about 20 cubic centimeters in the golf club head. In other words, the volume defined by the grooves **1501-1503** and **1551-1554** may be about 20 cubic centimeters. Accordingly, the golf club head may be constructed to be as large as a golf club head having a volume of 480 cubic centimeters, yet have a volume of 460 cubic centimeters by having the grooves **1501-1503** and **1551-1554**. Thus, the grooves **1501-1503** and **1551-1554**, or any grooves formed on a golf club head as described herein, allow a golf club head to be made larger without exceeding a certain volume limitation. According to another example, a golf club head may be constructed having a volume of 478 cubic centimeters. By forming the grooves **1501-1503** to define a volume of 4 cubic centimeters and the grooves **1551-1554** to define a volume of 6 cubic centimeters, the volume of the golf club head may be reduced to 468 cubic centimeters and yet have generally the same size as a club head having a volume of 478 cubic centimeters.

FIG. **42** shows an enlarged view of the groove **1504** to illustrate an exemplary shape of the grooves **1501-1503** and **1551-1554**. However, the grooves **1501-1503** and **1551-1554** may be in any configuration. Each groove **1501-1503** and **1551-1554** is defined by an end wall **1560**, two side walls **1562** and a bottom **1564**. The side walls **1562** diminish in height from the end wall **1560** to a groove side portion **1566**, at which the bottom **1564** transitions to the surface of the sole **1008** of the golf club. Accordingly, the depth of each groove increases from the groove side portion **1566** to the end wall **1560**. The bottom **1564** may have generally the same width or slightly varying width along the length of the groove as shown in the example of FIG. **42**. The side walls **1562** may be perpendicular to the bottom **1564** and the end wall **1560**. Alternatively, the side walls **1562** may be non-perpendicular relative to the bottom **1564** and the end wall **1560**. The side walls **1562** may have similar or dissimilar lengths or depths. The end wall **1560**, the side walls **1562** and the bottom **1564** may have any configuration so that a certain groove shape defining a certain volume is provided. In contrast to the grooves **1401-1404** and **1451-1454**, which diminish in depth along the length of the grooves, the grooves **1501-1503** and **1551-1554** diminish in depth along the width of the grooves.

The grooves **1501-1503** and **1551-1554** may increase the rigidity or stiffness of the sole **1008** of a golf club head by functioning as reinforcing ribs. The increased rigidity may be provided by the shape of the grooves as defined by the angled connections between the end wall **1560**, the side walls **1562** and the bottom **1564**. The increased rigidity of the sole **1008** of a golf club head may prevent denting of the golf club head due to impact with a golf ball, possible impact with the ground, possible impact with an object other than a golf ball, and/or repeated use. Furthermore, the increased rigidity of the sole **1008** may allow the sole **1008** of a golf club head to be constructed with a reduced thickness to reduce the weight of a golf club head without affecting the structural integrity of the golf club head. Changing the thickness of the sole **1008** of a golf club may also affect the sound characteristics of the golf club. For example, the thickness of the sole **1008** may directly affect the frequency and/or the amplitude of the sound wave produced by a golf club head when impacting a ball. A thinner sole **1008** may produce a lower frequency sound, i.e., lower pitch, while a thicker sole **1008** may produce a higher frequency sound, i.e., higher pitch. Accordingly, by providing the grooves **1501-1503** and **1551-1554** and/or any of the disclosed grooves on a golf club head, the thickness of the sole **1008** or other portions of the golf club head may be determined so that a certain sound is produced by the golf club head when impacting a golf ball.

The grooves **1501-1503** and/or the grooves **1551-1554** may be configured to provide certain sound characteristics for a golf club head. Changing the width, length and/or depth profile characteristics of one or more of the grooves and/or changing the distance between each groove may change the frequency and/or amplitude of the sound waves produced when the golf club head strikes a golf ball. For example, a plurality of deep and/or wide grooves may produce a lower frequency sound while a plurality of shallow and/or narrow grooves may produce a high frequency sound. In another example, placing the grooves closer together may produce a higher frequency sound while placing the grooves farther apart may produce lower frequency sound. Accordingly, the grooves **1501-1503**, **1551-1554** and/or any of the disclosed grooves on a golf club head can be configured so that a certain sound is produced by the golf club head when impacting a golf ball.

Referring to FIGS. **43** and **44**, a golf club head having a plurality of crown turbulators **1600** (e.g., two or more turbulators) according to another example is shown. The golf club head shown in FIGS. **43** and **44** is similar in many respects to the golf club head **100** of FIGS. **9** and **10**. Accordingly, except for the turbulators **1600**, same parts of the golf club head of FIGS. **43** and **44** and the golf club head **100** of FIGS. **9** and **10** are referred to with the same reference numbers. The turbulators **1600** may be defined by a plurality of ridges **1601-1606** that are positioned at or near the leading edge **112** and extend toward the separation region **120** or toward the rear **109** of the golf club head **100**. The ridges **1601-1606** may also be referred to herein as turbulators **1601-1606**. The ridges **1601-1606** may extend into the separation region **120**. While FIGS. **43** and **44** may depict a particular configuration and number of ridges, the apparatus, methods and articles of manufacture described herein may include different configuration and/or more or less number of ridges.

Referring also to FIG. **45**, any one or all of the ridges **1601-1606** may be positioned on the crown **110** as close as possible to the leading edge **112** or at least partly on the leading edge **112** such that a leading edge portion **1612** of each of the ridges **1601-1606** does not extend beyond a leading edge plane **1614**. The leading edge plane **1614** may be defined as a plane that is tangent to a portion of the leading edge **112** of the golf club head **100** or a location on the golf club head **100** where the crown **110** meets the club face **102**. The leading edge plane **1614** defines a leading edge angle **1616** relative to a loft plane **1618**. The loft plane **1618** may be a plane that defines or is tangent to a geometric center of the club face **102**. Any one or all of the ridges **1701-1706** may be at least partly located on the leading edge **112** and extend beyond the leading edge plane **1614** (i.e., at least partly located between the leading edge plane **1614** and the loft plane **1618**). The leading edge angle **1616** may range from 0°, which corresponds to the angle of the loft plane **1618**, to any angle greater than 0°. For example, the leading edge angle **1616** may be greater than or equal to 30° but less than or equal to 90°, greater than or equal to 45° but less than or equal to 90°, greater than or equal to 60° but less than or equal to 90°, or greater than 75° but less than or equal to 90°.

Each of the ridges **1601-1606** may have any length, width, height and/or cross-sectional profile, such as any profile as described herein. As described above, each ridge **1601-1606** may be positioned at or near the leading edge **112** and may extend toward the separation region **120** or toward the rear **109** of the golf club head. In the example of FIGS. **43** and **44**, each ridge **1601-1606** extends from the leading edge **112** toward the rear **109** of the golf club head **100** with a portion of each ridge being located on the leading edge **112**. Each of the ridges **1601-1606** may have a greater width and height at the leading edge **112** than other parts of the ridge. Furthermore, the width and height of each of the ridges **1601-1606** may diminish from the leading edge **112** toward the rear **109** of the golf club head. In the examples of FIGS. **43** and **44**, each ridge **1601-1606** includes a front surface **1620**. The front surface **1620** of each ridge defines the most forward portion or front portion of the ridge. Although the most forward portion of a ridge is referred to herein as a front surface **1620**, such a forward portion may be defined by one or more flat continuous or discontinuous surfaces, one or more continuous or discontinuous curved surfaces, one or more blunt or sharp edges, points, or a combination thereof. A portion or the entire front surface **1620** of each ridge may define a portion of the leading edge plane **1614**, be spaced apart from but generally parallel to the leading edge plane **1614**, or be spaced apart from and generally non-parallel to the leading edge plane **1614**. According to one embodiment, the front surface **1620** may be positioned and configured such that any portion of the front surface **1620** may not extend beyond or through the leading edge plane **1614** that corresponds to the ridge defining the front surface **1620**. The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

Referring to FIG. **46-49**, several examples of configurations, positions and angles of the front surface **1620** relative to the leading edge plane **1614** and/or the loft plane **1618** are shown. A certain leading edge angle **1616** may be required by one or more golf governing bodies. For example, a golf governing body may require that the crown **110** or the leading edge **112** of a golf club head does not include any objects or projections that extend beyond the leading edge plane **1614** having a certain leading edge angle **1616** relative to the loft plane **1618**. In the example of FIGS. **46-49**, the leading edge plane **1614** forms a leading edge angle **1616** of about 30° with the loft plane **1618**. Thus, according to the examples of FIGS. **46-49**, any turbulator **1600** located on or near the leading edge **112** may not have any portion thereof extend beyond the leading edge plane **1614**. The leading edge angle **1616** may be any angle (e.g., 30°, 45°, 60°, etc.). Accordingly, describing a certain angle for the leading edge angle **1616**, such as an angle of about 30° is exemplary and in no way limits the leading edge angle **1616** to a certain angle.

Referring to the example of FIG. **46**, the front surface **1620** or at least a cross-sectional portion of the front surface **1620** may generally define the leading edge plane **1614**. Accordingly, the front surface **1620** is positioned as forward or near the face **102** of the golf club head as possible since any further forward positioning of the front surface **1620** would cause the front surface **1620** to extend beyond the leading edge plane **1614**.

Referring to the example of FIG. **47**, the front surface **1620** or at least a cross-sectional portion of the front surface **1620** may be generally parallel to the loft plane **1618**. Accordingly, the front surface **1620** may be positioned behind or aft of the leading edge **112** so that no portion of the front surface **1620** extends beyond the leading edge plane **1614**.

Referring to the example of FIG. **48**, the front surface **1620** or at least a cross-sectional portion of the front surface **1620** extends from the leading edge **112** at an angle that is greater than the leading edge angle **1616**. As shown in FIG. **48**, however, a portion of the front surface **1620** may be tangent to the leading edge plane **1614**. In other words, the front surface **1620** may extend from the leading edge **112**, or as close to the leading edge **112** as possible, toward the rear **109** of the golf club head **100** at an angle that is greater than the leading edge angle **1616** without extending beyond the leading edge plane **1614**.

Referring to the example of FIG. **49**, the front surface **1620** or at least a cross-sectional portion of the front surface **1620** extends from the leading edge **112** at an angle that is greater than the leading edge angle **1616**. As shown in FIG. **47**, however, a portion of the front surface **1620** may be tangent to the leading edge plane **1614**. In other words, the front surface **1620** may extend from the leading edge **112**, or as close to the leading edge **112** as possible, toward the back of the crown **110** at an angle that is greater than the leading edge angle **1616** without extending beyond the leading edge plane **1614**.

In the example of FIG. **47**, at least a portion of the front surface **1620** or a cross section of at least a portion of the front surface **1620** may be curved, i.e., non-planar. The curvature of the front surface **1620** may vary in any direction, such as from the toe end **106** to the heel end **104**.

The turbulators **1600** may be positioned at any location on the crown **110** so that a portion of the front surface **1620** of at least one of the turbulators **1600** is tangent to or is positioned aft of a leading edge plane **1614**. The leading edge angle **1616** may be within any range, such as 0° to 90°. For example, as shown in the example of FIG. **46**, a portion of the front surface **1620** of at least one turbulator **1600** may be located at the leading edge **112** of a golf club head **100**. Alternatively, a portion of the front surface **1620** of at least one turbulator **1600** may be located aft of the leading edge **112** of a golf club head **100** as shown in FIGS. **47-49**.

The turbulators **1600** may be sized, shaped and/or positioned on the crown **110** to provide any type of air flow properties over the crown **110**. Each turbulator may have a certain length, width, height, longitudinal shape, cross-sectional shape, surface properties (i.e., texture or frictional properties), angular orientation, or any other physical characteristics that may provide certain flow characteristics over the crown **110**. Examples of turbulator characteristics are provided in FIGS. **11-14**. In the example of FIGS. **43** and **44**, the ridge **1601** is longer than the ridges **1602-1606**. Additionally, the turbulator **1601** has a greater curvature than the turbulators **1602-1606**. Furthermore, the lengths and curvatures of the ridges **1601-1603** decrease from the toe end **106** to the center of the crown **110**, while the lengths and curvatures of the turbulators **1604-1606** vary from the center of the crown **110** to the heel end **104**.

The characteristics of each turbulator may depend on the profile of the separation region and the change in the location and the profile of the separation region during the entire golf club swing. For example, air flow separation may be greatest near the toe end **106** and decrease in a direction from the toe end **106** to the center of the crown **110**. Accordingly, as shown in FIG. **44**, the configuration of each of the turbulators **1601-1603** may be determined to delay separation along the profile of the separation region from the toe end **106** to the center of the crown **110**. Thus, turbulators according to the disclosure may have any physical characteristics and be located at any location on the crown so as to provide delay in airflow separation on the crown for the entire golf swing.

Each ridge **1601-1606** may be oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. Each ridge **1601-1606** may be curved, have variable base width along the length of the ridge, have variable cross-sectional shapes, have variable height along the length of the ridge and/or the width of the ridge, have sharp or blunt edges, front surfaces and/or trailing edges, have sharp or blunt tops, have different surface textures, and/or have other physical variations along the length, the width and/or the height of the ridge. The ridges **1601-1606** of the turbulators **1600** may be similar in many respects to other ridges of the turbulators according to the disclosure.

Referring to FIG. **50**, a golf club head having a plurality of crown turbulators **1650** (e.g., two or more turbulators) according to another example is shown. The golf club head shown in FIG. **50** is similar in many respects to the golf club head **100** of FIGS. **9** and **10**. Accordingly, except for the turbulators **1650**, same parts of the golf club head of FIG. **50** and the golf club head **100** of FIGS. **9** and **10** are referred to with the same reference numbers. The turbulators **1600** may be defined by a plurality of ridges **1651-1656** that are positioned at or near the leading edge **112** and extend toward the separation region **120** or toward the rear **109** of the golf club head **100**. The ridges **1651-1656** are similar in many respects to the ridges **1601-1606** described in detail above. Therefore, a detailed description of the ridges **1651-1656** is not described in detail herein for brevity.

Each ridge **1651-1656** may be oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. For example, each ridge **1651-1656** may be oriented at an angle that may in a range of about 20° to about 70° relative to the leading edge **112**. In the example of FIG. **50**, the ridges **1651-1656** are oriented at an angle of about 70° relative to the leading edge **112**. Each ridge **1651-1656** may be curved, have variable base width along the length of the ridge, have variable cross-sectional shapes, have variable height along the length of the ridge and/or the width of the ridge, have sharp or blunt edges, front surfaces and/or trailing edges, have sharp or blunt tops, have different surface textures, and/or have other physical variations along the length, the width and/or the height of the ridge. The ridges **1651-1656** may be similar in many respects to other ridges of the turbulators according to the disclosure.

Referring to FIGS. **51** and **52**, a golf club head having a plurality of turbulators **1700** according to another example is shown. The golf club head of FIGS. **51** and **52** is similar in many respects to the golf club head **100** of FIGS. **9** and **10**. Accordingly, except for the turbulators **1700**, same parts of the golf club head **100** of FIGS. **51** and **52** and the golf club head **100** of FIGS. **9** and **10** are referred to with the same reference numbers. The turbulators **1700** are defined by a plurality of grooves **1701-1706** that are positioned at or near the leading edge **112** and extend toward the separation region **120** or toward the rear **109** of the golf club head **100**. The grooves **1701-1707** may also be referred to herein as turbulators **1701-1706**. The grooves **1701-1706** may extend into the separation region **120**. While FIGS. **51** and **52** may depict a particular number of grooves, the apparatus, methods and articles of manufacture described herein may include more or less number of grooves.

Any one or all of the grooves **1701-1706** may be positioned on the crown **110** as close as possible to the leading edge **112** or at least partly on the leading edge **112** such that each groove does not extend beyond the leading edge plane **1614** (shown in FIG. **45**). Alternatively, any one or all of the grooves **1701-1706** may be at least partly located on the leading edge **112** and extend beyond the leading edge plane **1614** (i.e., at least partly located between the leading edge plane **1614** and the loft plane **1618**). Each of the grooves **1701-1706** may have any length, width, depth and/or cross-sectional profile, such as any profile according to the disclosure. As described above, each groove may be positioned at or near the leading edge **112** and extend toward the separation region **120** or the rear **109** of the golf club head **100**. In the example of FIGS. **51** and **52**, each groove extends from the leading edge **112** toward the rear **109** of the golf club head **100** with a portion of each groove being located on the leading edge **112**. Each of the ridges **1701-1706** may have a greater width and depth at the leading edge **112** than other parts of the grooves. Furthermore, the width and depth of each of the grooves **1701-1706** may diminish from the leading edge **112** toward the rear **109** of the golf club head **100**.

The turbulators **1700** may be sized, shaped and positioned on the crown to provide any type of air flow properties over the crown. Each turbulator **1700** may have a certain length, width, depth, longitudinal shape, cross-sectional shape, surface properties (i.e., texture or frictional properties), angular orientation, or any other physical characteristics that may provide certain flow characteristics over the crown. In the example of FIGS. **51** and **52**, the turbulator **1701** is longer than the turbulators **1702-1706**. Additionally, the turbulator **1701** has a greater curvature than the turbulators **1702-1706**. Furthermore, the lengths and curvatures of the turbulators **1701-1703** decrease from the toe end **106** to the center of the crown **110**, while the lengths and curvatures of the turbulators **1704-1706** vary from the center of the crown **110** to the heel end **104**. The characteristics of each turbulator may depend on the profile of the separation region and the change in the location and the profile of the separation region during the entire golf club swing. For example, air flow separation may be greatest near the toe end **106** and reduce in a direction from the toe end **106** to the center of the crown **110**. Accordingly, as shown in FIG. **52**, the locations and physical properties of the turbulators **1701-1703** may be determined to delay separation along the profile of the separation region from the toe end **106** to the center of the crown **110**. Thus, turbulators according to the disclosure may have any physical characteristics and be located at any location on the crown so as to provide delay in airflow separation on the crown for the entire golf swing.

Each groove **1701-1706** may be oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. For example, each groove **1701-1706** may be oriented at an angle between 20° and 70° relative to the leading edge **112**. Each groove **1701-1706** may be curved, have variable base width along the length of the grooves, have variable cross-sectional shapes, have variable depth along the length of the groove and/or the width of the groove, have sharp or blunt groove edges, have different surface textures, and/or have other physical variations along the length, the width and/or the depth of the groove.

A club head may include one or a combination of the turbulators **300**, **400**, **500**, **600**, **1200**, **1300**, **1600** and/or **1700**; and/or grooves **1400** and **1500**. For example, a club head may include the turbulators **400** on the crown and turbulators **1200** on the sole. In another example, a club head may include the turbulators **500** on the crown and turbulators **1200** and **1300** on the sole. Thus, any combination of turbulators according to the disclosure may be provided on the crown and/or the sole to provide a particular flow pattern on the club head. Furthermore, any combination of turbulators as described herein may be provided with the grooves on the sole **1008** of the golf club head according to the examples of FIGS. **39** and **40**. Any or a combination of the methods described herein for forming ridges or grooves may be used to form any of the ridges or grooves according to the disclosure.

Any reference made herein to certain parts of a golf club head such as a face, a rear, a heel or heel end, a toe or toe end, a crown and a sole of a golf club head may refer to portions of the golf club head that generally represent those parts.

Although a particular order of actions is described above for making turbulators or club heads with turbulators, these actions may be performed in other temporal sequences. For example, two or more actions described above may be performed sequentially, concurrently, or simultaneously. Alternatively, two or more actions may be performed in reversed order. Further, one or more actions described above may not be performed at all. The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

Although certain example systems, methods, apparatus, and articles of manufacture have been described herein, the scope of coverage of this disclosure is not limited thereto. On the contrary, this disclosure covers all systems, methods, apparatus, and articles of manufacture fairly falling within the scope of the appended claims either literally or under the doctrine of equivalents.

What is claimed is:

1. A golf club head comprising:

a face portion defining a loft plane, a rear portion opposite to the face portion, a heel portion, a toe portion opposite to the heel portion, a crown portion having a crown surface extending between the face portion, the rear portion, the heel portion and the toe portion, a sole portion opposite to the crown portion and having a sole surface extending between the face portion, the rear portion, the heel portion and the toe portion, and a leading edge portion between the face portion and the crown portion, the leading edge portion defining a leading edge plane forming a leading edge angle with the loft plane; and

a plurality of crown turbulators disposed on the crown surface, each crown turbulator having a front portion defining a portion of the crown turbulator being closest to the face portion, the front portion of at least one of the plurality of crown turbulators being at least partly located on the leading edge portion and between the leading edge plane and the rear portion, but not extending beyond the leading edge plane;

wherein:

the leading edge angle is greater than or equal to 30 degrees and less than or equal to 90 degrees.

2. The golf club of claim **1**, wherein the leading edge angle is around 30°.

3. The golf club of claim **1**, wherein the leading edge angle is around 45°.

4. The golf club of claim **1**, wherein at least one of the plurality of crown turbulators comprises at least one of a projection on the crown surface or a groove on the crown surface.

5. The golf club of claim **1**, wherein the length of each of the plurality of crown turbulators is oriented relative to the face portion at an angle of between around 20° and around 70°.

6. The golf club of claim **1** further comprising a plurality of grooves in a portion of the sole surface, wherein a reduction in volume of the golf club head by having the plurality of grooves allows the size of the golf club head to be enlarged without substantially changing the volume of the golf club head.

7. A golf club head comprising:

a face portion defining a loft plane, a rear portion opposite to the face portion, a heel portion, a toe portion opposite to the heel portion, a crown portion having a crown surface extending between the face portion, the rear portion, the heel portion and the toe portion, a sole portion opposite to the crown portion and having a sole surface extending between the face portion, the rear portion, the heel portion and the toe portion, and a leading edge portion between the face portion and the crown portion, the leading edge portion defining a leading edge plane forming a leading edge angle with the loft plane; and

a plurality of crown turbulators disposed on the crown surface, each crown turbulator having a front portion defining a portion of the crown turbulator being closest to the face portion, the front portion of at least one of the plurality of crown turbulators being at least partially located on the leading edge portion and between the leading edge plane and the rear portion, but not extending beyond the leading edge plane;

a plurality of crown turbulators on the surface of the crown portion, each adjacent pair of crown turbulators being separate and spaced apart and extending generally in a direction from the face portion to the rear portion; and

a plurality of grooves in a portion of the sole surface, the plurality of grooves configured to reduce the volume of the golf club head and allow the size of the golf club head to be enlarged without substantially changing the volume of the golf club head;

wherein:

the leading edge angle is greater than or equal to 30 degrees and less than or equal to 90 degrees.

8. The golf club head of claim **7**, wherein the plurality of grooves comprise:

a first plurality of grooves disposed in a portion of the sole surface between the heel portion and a centerline extending from a center portion of the face portion to the rear portion; and

a second plurality of grooves disposed in a portion of the sole surface between the toe portion and the centerline.

9. The golf club head of claim **7**, wherein the plurality of grooves define a volume of about 20 cubic centimeters.

10. The golf club head of claim **7**, wherein the plurality of grooves define a volume of about 10 cubic centimeters to about 20 cubic centimeters.

11. The golf club head of claim **7**, wherein the plurality of grooves stiffens the sole portion.

12. A method for forming a golf club head comprising:

forming a face portion defining a loft plane, a rear portion opposite to the face portion, a heel portion, a toe portion opposite to the heel portion, a crown portion having a crown surface extending between the face portion, the rear portion, the heel portion and the toe portion, a sole portion opposite to the crown portion and having a sole surface extending between the face portion, the rear portion, the heel portion and the toe portion, and a leading edge portion between the face portion and the crown portion, the leading edge portion defining a leading edge plane forming a leading edge angle with the loft plane; and

forming a plurality of crown turbulators disposed on the crown surface, each crown turbulator having a front portion defining a portion of the turbulator being closest to the face portion, the front portion of at least one of the crown turbulators being at least partly located on the leading edge portion and between the leading edge plane and the rear portion, but not extending beyond the leading edge plane;

wherein:

the leading edge angle is greater than or equal to 30 degrees and less than or equal to 90 degrees.

13. The method of claim **12**, wherein the leading edge angle is around 30°.

14. The method of claim **12**, wherein the leading edge angle is around 45°.

15. The method of claim **12**, wherein forming at least one of the plurality of crown turbulators comprises forming at least one of a projection on the crown surface or a groove on the crown surface.

16. The method of claim **12**, wherein the length of each crown turbulator is oriented relative to the face portion at an angle of between around 20° and around 70°.

17. The method of claim **12** further comprising increasing the size of the golf club head without substantially increasing the volume of the golf club head by forming a plurality of grooves in a portion of the sole surface.

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